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Study Planning of Check Dam Using Waste Tires at Sumbersari UB Forest Area

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A B S T R A C T

A check dam is a construction solution to overcome various catchment area challenges, especially erosion and sedimentation control in the upstream region. The strategic implementation of this plan includes various methodologies such as topographic, geotechnical identification, hydrological analysis, sedimentation analysis, material specification, hydraulic analysis, stability analysis, storage capacity analysis, and budget plan development. The purpose of this research is to check dam planning using waste tires which includes sediment discharge, detailed dimensions of the building, and building safety, to the required cost budget plan by reviewing the aspects of environmentally friendly, low cost, and waste utilization by sustainable development goals. The type of sediment flow that occurs is debris flow with a sediment discharge rate of 25,939 m^3/s, due to the flood discharge phenomenon with a significant 25-year return period is 10,580 m^3/s. The safety number of the proposed check dam design using the calculation of forces acting and Plaxis 2D V20 software has exceeded the safety permit requirements with various conditions that may occur at the study site. In a single flood, this check dam can effectively mitigate for approximately 4 days. To implement this development plan, an estimated budget of IDR773.472.940 has been projected.

1. Introduction

One of the serious problems worrying the earth's land at this time especially due to uncertain rain intensity (climate change effect) is erosion. Other factors that cause erosion include slope, vegetation, soil and geological characteristics, and human activities. If left unchecked and no immediate countermeasures are taken, the land will be depleted in the long run. So, the output of this erosion causes changes in river morphology with steep bed slopes and triggers a significant buildup of sediment downstream. Likewise, the upstream slopes of Mount Arjuno, the Sumbersari UB Forest area, which is characterized by steep river slopes, have the potential for erosion, especially when there is high-intensity rain and flood. Flooding is a form of water damage that causes rivers to spillways and watershed natural events that can result in property and object losses including infrastructure [1]. According to residents, damage to infrastructure such as bridges has occurred there due to floods that not only carry sand, but also trees or branches, gravel, and rocks downstream.

Capturing sediment inflow using check dams is an effort to reduce the amount of sediment entering the river body [2]. A Check dam is a water building placed in a river upstream that has functions including retaining, controlling the speed, discharge, direction of sediment flow, and being able to

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accommodate sediment permanently or temporarily [3]. Check dams not only reduced the total volume of floods but also increased the flood duration to delay the occurrence of flood peaks [4] and support agriculture activities [5]. So that it can reduce the magnitude of the level of erosion or land degradation.

The damage caused by erosion certainly requires a lot of money to rehabilitate or renovate the area. So moderate to light financing is needed in the development of water resources infrastructure while still paying attention to environmental conservation. In addition, the building planning design must also pay attention to the minimum potential for structural failure.

Along with the increasing number of vehicles, the quantity of waste tires is also increasing. Waste tires and their accumulation are a global environmental problem in that they are non-biodegradable, global, and an estimated 1,5 billion are generated each year [6]. Considering the aspects of environmentally friendly, low budgeting, and utilization of used materials which are part of sustainable development goals, one technology that is suitable for erosion control efforts in the Sumbersari UB Forest Area is the construction of Check Dam using waste tires. So the purpose of this research is to get a check dam planning using waste tires start from sediment discharge is entering calculation until the required cost budget plan to be applicable and prevent when debris flow occurs.

2. Research Method

Based on the objectives and issues raised, this research is included in quantitative research. This research aims to obtain a waste tire check dam planning design whose stability is safe and sustainable. This research was conducted in Curah Bok Kembar River, Arjuno Mountain upstream slope, The UB Forest Area of Sumbersari Hamlet, Tawang Argo Village, Karangploso District, Malang Regency. Geographically, the exact location of the check dam planning is located at the coordinates 7°49'27,081" S and 112°34'49,44" E. The type of data used is secondary data. Data collection was obtained from agencies and previous research websites. After collecting secondary data, data processing was carried out which included topographic identification, geotechnical identification, hydrological analysis, sedimentation analysis, material specification analysis, hydraulics analysis, storage capacity analysis, stability analysis, and budget plan development.

Source: Google Earth and Overlay Research Result Used ArcGIS 10.8 (2024).

Figure 1. Study Planning Location Point With Catchment Area

3. Description and Technical

1. Data Collection Techniques

   The following is the data collection method that will be carried out in this study by submitting data requests to :

   a. Topographic and geotechnical data sourced from previous research by Nabila Oktaviariyadi in 2022 at the same location.

   b. Rainfall data sourced from the agency: East Java Provincial Water Resources Public Works Office with the determination of the nearest rain station point sourced from the BMKG Karangploso Jawa Timur website.

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c. Land use data sourced from the Indonesia Geospatial website in the form of Shape File Malang District
d. Used tire material specification data sourced from surveys, interviews, and internet literature to trigger ideas, especially types and fittings.

2. Instrument Analysis tool

To get the boundaries of the catchment area and know the area distribution of each type of land use that is included in it, overlay processing is needed using ArcGIS 10.8 software.

To calculate the amount of displacement that occurs in the building and produce a factor of safety (SF) in stability analysis, Plaxis 2D V20 software is used. Overall, the process of using Plaxis 2D V20 software is carried out with 5 stages including soil or material parameter input, structure depiction, mesh distribution, flow condition input, and stage construction with various phase conditions.

While other processing is used Microsoft Excel software for calculation and AutoCAD for drawing.

3. Data Analysis Techniques

a. Topography And Geotechnical Identification

Topographic identification is intended to obtain the slope, original river width, and elevation real of the study site from identification Google Earth and the measurement results of previous research surveys [7]. Then these things can be used for the drawing of cross-sections and completeness of the pieces of the building.

Geotechnical identification here includes collecting previously conducted test data as required and recapitulating all the tests. The required test data includes grain classification from gradation and hydrometer tests, specific gravity, bulk density, water content, cohesion, and friction angle [7].

b. Hydrological Analysis

The stages of hydrological analysis include delineation of the catchment area according to the planning point, determination of influential rainfall stations using the Thiessen polygon method, data consistency test, analysis of regional average rainfall, analysis of design rainfall using Gumbel and Log Pearson III methods, distribution suitability test using the Chi-Square and Smirnov-Kolmogorov methods, and analysis of design flood discharge using the rational method. The rainfall stations that affect the catchment area and were tested for data quality using the RAPS consistency test are Ngujung Station and Tinjumoyo Station (According to **Figure 1**).

Rational Method Equation [8] :

$$Q = 0{,}278 \times C \times I \times A \tag{1}$$

Note: Q is peak flood discharge (m^3/s), C is runoff coefficient, I is rainfall intensity (mm/hour), A is catchment area (km^2)

c. Sedimentation Analysis

Sedimentation analysis is needed to determine the amount of sediment discharge with stages including determining the nature of sediment flow, calculating sediment discharge, and designing discharge using the Takahashi approach [9] [10].

To determine the nature of sediment flow, classified as debris flow if :

$$\tan\theta > \frac{c*(\sigma-\rho w)\tan\emptyset}{c*(\sigma-\rho w)+\rho w\,(1+\frac{h}{d})} \tag{2}$$

Note: θ is riverbed slope angle (°), c* is grain concentration in sediment (0,6), σ is debris density (ton/m^3), ρw is water density (ton/m^3), $\emptyset$ is friction angle (°), h is historical flood water depth (m), and d is diameter of riverbed granules D_{50} (mm).

To calculate sediment discharge as follows :

$$Cd = \frac{\rho d.\tan\emptyset}{(\sigma-\rho d)(\tan\emptyset-\tan\theta)} \tag{3}$$

$$Qs = \frac{C*}{(c*-Cd)}Cd.Qw \tag{4}$$

Note: ρd is material density (ton/m^3), Cd is volumetric sediment concentration, and Qw is peak flood discharge (m^3/s). If the calculated Cd > 0,8 C* then the Cd used in the calculation of Qs is 0,8 C*.

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Last, to get design discharge use peak debris discharge before calculating the dimension check dam :

$$Cd = \frac{\rho \tan \theta}{(\sigma - \rho)(tan\emptyset - tan\ \theta)} \quad (5)$$

$$\alpha = \frac{C^*}{C^* - Cd} \quad (6)$$

$$Qd = \alpha . Q \quad (7)$$

Note: ρ is water density (ton/m^3), α is sediment content coefficient, and Q is peak flood discharge (m^3/s)

d. Material Spesification Analysis
The material used as a constituent of the check dam building in this study uses whole truck tires without wheels with a standard size of 7.50 - 16. This type was chosen because many people use it in the field. While the binder and filler of the tire is K-175 quality concrete mortar. Specification or dimension size from the tire is shown in **Figure 2**. The preparation of tires is planned in a sleeping position [11]. This position is like "2 in 1" which means every 2 tires are parallel to one tire on top.

e. Check Dam Structure Planning (Hydraulic Analysis)
The hydraulics analysis of the check dam includes planning the dimensions of the structure. The calculation to obtain the dimensions of the structure is based on [3].
To get the overall check dam dimensions hydraulically and empirically starts from knowing the water level above the spillway using the following equation:

$$Q = \frac{2}{15} C\sqrt{2g}(3B_1 + 2(B_1 + 2\ m\ h_3))h_3^{\frac{3}{2}} \quad (8)$$

Note: Q is peak design discharge (m^3/s), C is spillway coefficient (0,6-0,68), g is gravitational acceleration (9,81 m/s^2), B_1 is bottom spillway width (m), m is cross-section slope, and h_3 is water level above the spillway (m). The result of the water level above the spillway can be validated by rating the curve method.

f. Stability Analysis
Stability analysis is divided into two, namely based on the method of calculating the forces that work manually and software assistance with several conditions that can occur in the field. Based on this manual calculation method, the analysis carried out is stability to shear, overturning, and foundation bearing capacity. The method with the help of Plaxis 2D V20 software carried out stability analysis of total displacement by their finite element method [12].

g. Storage Capacity Analysis
The parameters used to obtain the storage capacity include the original riverbed slope, river width, and main dam height [13]. Then the storage capacity is divided by the estimated volume of debris flow (Vec) that enters the dam using Mizuyama's Method [14].

$$\text{Vec} = \frac{R_{24} x A x 10^3}{1-\lambda} x \frac{Cd}{1-Cd} x Fr \quad (9)$$

$$Fr = 0{,}05\ (\log \text{A} - 2)^2 + 0{,}05 \quad (10)$$

Note: R_{24} is the maximum daily rainfall (mm), λ is the void ratio ($\pm$0,4), and Fr is the debris flow correction coefficient.

h. Budget Plan Development
The analysis of the cost budget plan starts from the calculation of the unit price of work and materials. This refers to the regulation of the Minister of Public Works and Public Housing Number 8 of 2023 [15] and the unit price of labor based on the regulations of the mayor of Malang Number 10 of 2022 [16].

4. Results and Discussions

4.1. Topography Analysis

Geographically, the check dam planning location has contoured characteristics with land elevations ranging from +1144 to +1146 above sea level"." On the right and left sides of the cliff, there are large rocks that can later be used as reinforcement or building support. The location has a land slope of 25,5% or 14,28 degrees and a river width of 5,772 meters. The location for planning the check dam

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is shown in **Figure 1**. Based on the overlay results of combining the Catchment Area and land use type data of Malang District, a catchment area of 224,26 hectares was obtained. The percentage and types of land use include forests (77,92%), shrubs (21,83%), and fields (0,25%).

4.2. Geotechnical Analysis

This analysis is used to determine the characteristics of soil properties at the check dam planning location. The results of geotechnical testing in the research used as the source of this study and have been recapitulated can be seen in **Table 1**.

Table 1. Field Geotechnical Test Result Data.

No	Sample Name	Test Result Geotechnical Data							
		Spesific Gravity (g/cm^3)	Bulk Density (g/cm^3)	Gradation and Hydrometer Test Classification Granules (%)				Direct Shear	
		Gs	γ	Gravel	Sand	Clay	Silt	C (kg/cm^2)	Ø(°)
1	CP 9 Basic	2,354	1,128	0	25,301	11,978	67,721	0,058	34,24
2	CP 9 Right	2,440	0,983	4,918	38,525	8,334	48,224	-	-
3	CP 9 Left	2,316	1,128	27,011	52,299	6,717	13,973	-	-

Source: Oktaviariyadi (2022) and Personal Analysis (2023)

4.3. Hydrological Analysis

Rainfall data is obtained from rainfall stations with a lot of data used for the last 15 years [17][18] from 2008 to 2022. Based on the calculation, the planned rainfall analysis is carried out by two widely used probability distribution models the Gumbel Distribution and Log Pearson III [19]. Subsequently, the suitability of the distributions was tested using the Chi-Square Test and the Smirnov-Kolmogorov Test [20], the result obtained is shown in **Table 2**.

The distribution Gumbel was chosen because rain distribution results are closer to the data in the field dan building safety considerations in the case of large flood discharges. Furthermore, the design flood discharge analysis uses the rational method because the catchment area is 224,26 hectares, which is less than 50 km^2. According to [21] on hydrological calculations for sabo, if the catchment area is less than 50 km^2, the rational method equation is used for flood discharge calculations by Equation 1.

From **Table 3**, the 25-year return period flood discharge value is 10,58 m^3/s, which will be used to calculate the design discharge.

Table 2. Recapitulation of Rainfall Probability Distribution Test.

Chi-Square Test Summary					
Probability Distribution	x2 Observed	Critical		Hypothesis	
		1%	5%	1%	5%
Gumbel	3,333	9,21	5,991	Accepted	Accepted
Log Pearson III	2,000	6,635	3,841	Accepted	Accepted
Smirnov Kolmogorov Test Summary					
Probability Distribution	P Max	Critical		Hypothesis	
		1%	5%	1%	5%
Gumbel	0,071	0,404	0,338	Accepted	Accepted
Log Pearson III	0,096	0,404	0,338	Accepted	Accepted

Source: Calculation Result (2023)

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Table 3. Recapitulation of Flood Discharge (Rational Method) with Various Return Periods.

Return Periods (year)	Rainfall (mm)	Tc (hour)	C	Rain Intensity (mm/hour)	Area (km^2)	Q (m^3/s)
2	76,112	0,57	0,294	38,576	2,243	7,078
5	91,186	0,57	0,294	46,216	2,243	8,480
10	101,166	0,57	0,294	51,275	2,243	9,408
25	113,776	0,57	0,294	57,666	2,243	10,580
50	123,130	0,57	0,294	62,407	2,243	11,450
100	132,416	0,57	0,294	67,114	2,243	12,314

Source: Calculation Result (2024)

4.4. Sedimentation Analysis

To determine the type of flow that occurs in the planned dam and calculate the design discharge, sedimentation analysis is required. Using geotechnical data and Equation 2, the result is 0,255 > 0,0029 which means the type of sediment flow is a debris flow. Meanwhile, the result calculation of sediment discharge using Equation 3 to 4 with flood discharge 25-year return obtained the peak discharge of debris flow is Qs = 25,393 m^3/s. The volumetric concentration of sediment moving in debris flow or Cd = 0,597 which means more than 0,8C* and so use value Cd = 0,48. The result of the recapitulation of the sediment discharge at each return period is shown in **Table 4**.

Table 4. Recapitulation of Sediment Discharge at Various Return Periods.

Return Periods (Year)	Rainfall (mm)	Flood Discharge (m^3/s)	Sediment Discharge (m^3/s)
2	76,11	7,078	16,987
5	91,19	8,480	20,351
10	101,17	9,408	22,578
25	113,78	10,580	25,393
50	123,13	11,450	27,480
100	132,42	12,314	29,553

Source: Calculation Result (2024)

The debris flow hydrograph containing sediment content at the flood peak for building dimension planning can be calculated using Equations 5 to 7. The result of the design discharge is obtained as Qd = 52,901 m^3/s which comes from the calculation of Cd = 0,48 and a = 5,00.

4.5. Check Dam Design Planning

The check dam was built using used tires filled with concrete mortar and has unit dimensions: diameter 0,787 m, width 0,1905 m, and thread depth = 0,0193 m. The specifications can be seen in **Figure 2**. The installation of tires was used because the check dam was built in a protected forest and reduced the stockpiling of used goods as support for the Sustainable Development Goals (SDGs), according to [22]. It is recommended to use conservation forest materials for infrastructure facilities and also provide efficient alternative building materials with very useful characteristics [23].

The density of the construction resulting from the combination of the two materials (waste tires and concrete mortar) that make up the check dam can be determined by depicting a review of the preparation of materials in a 1 m^3 cube.

Full Tire Volume	= 0,093 m^3
Volume of rubber per tire	= 0,028 m^3
Volume of mortar per tire	= 0,065 m^3
n tires per-m^3	= 8,5 tires
Volume of rubber per m^3 cube	= 0,234 m^3 or 23,39%
Volume of concrete mortar per m^3 cube	= 0,766 m^3 or 76,61%

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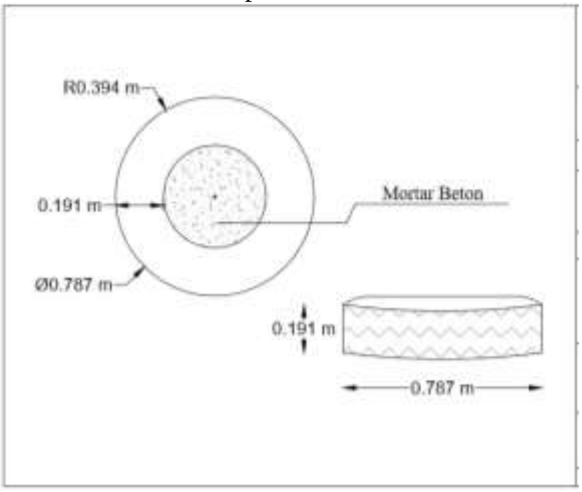
With γ Tire Rubber = 1,14 ton/m^3 [24], γ Normal Concrete Mortar = 2,20 ton/m^3 [25], and This percentage obtained a combined density of γ_{tc} = 1,95 ton/m^3. This means that the combined material has greater strength than using gabions in general with y = 1,5 ton/m^3 [26]. Then, the overall check dam design dimensions can be calculated and the resulting images are shown in **Figure 3** and **Figure 4** for cross-section depiction results of the main dam part.

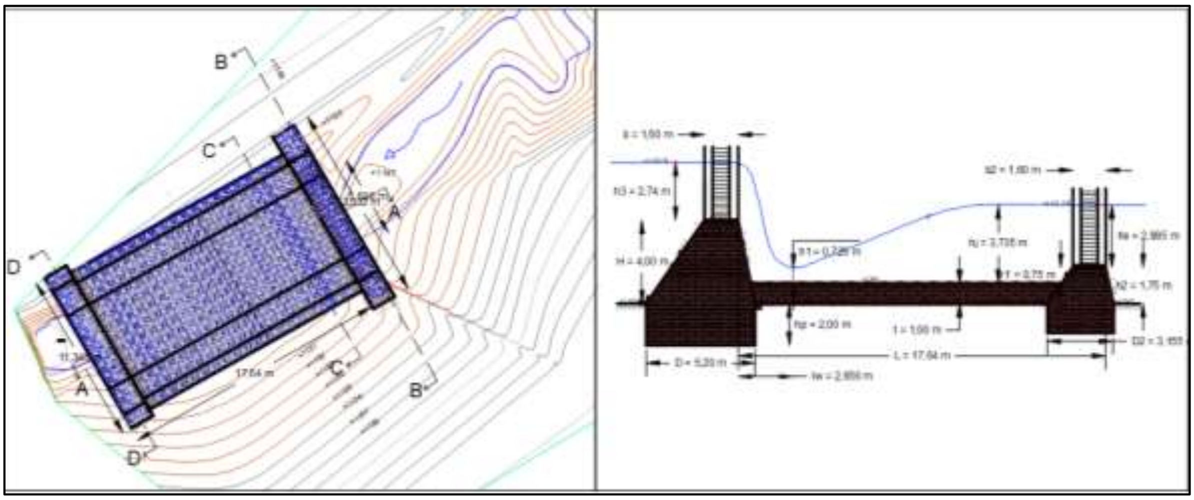


Source: Drawing Result (2024).

Figure 2. Planning Specifications Used 7.50-16 Type Waste Tires.

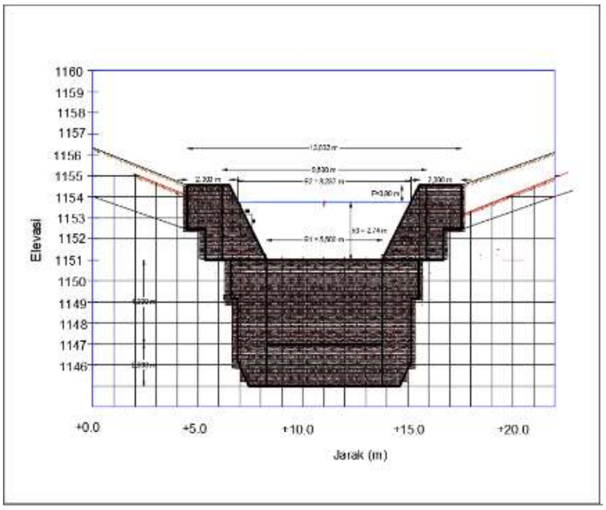
Based on [3], the recapitulation of check dam design results is as follows:

Bottom spillway width	= 5,5 m
Top spillway width	= 8,237 m
Flood Water Level	= 2,74 m (from Equation 8 with m = 0,5)
Main dam high	= 4 m
Freeboard high	= 0,8 m
Crest width	= 1,6 m
Spillway high	= 3,54 m
Upstream slope	= 0,7
Downstream slope	= 0,2
Thickness of Stilling Basin	= 1 m
Length of Stilling Basin	= 17,64 m
Sub dam high	= 1,75 m
Retaining wall high	= 5,5 m



Source: Drawing Result (2024)

Figure 3. Top View and Longitudinal Section of Waste Tires Check Dam Design



Source: Drawing Result (2024)

Figure 4. Cross Section of Waste Tires Main Dam Design.

With a total check dam storage capacity of 725,493 m^3 and an estimated incoming sediment debris flow volume of 73.013,504 m^3 from a calculation using Equations 9 to 10, the maximum storage life is 3,6 ~ 4 days for a single flood.

4.6. Stability Analysis

Based on the analysis of the forces acting in the main dam and wall edge [3][27][28] and the finite element processing module using Plaxis 2D V20 [12][29][30], the results are safe against various possible conditions in the field. Recapitulation of the results of stability calculations with manual and plaxis software assistance is presented in **Table 5** and **Table 6**. An example of an overview of the results/output of the stability analysis using Plaxis 2D V20 can be seen in **Figure 5**.

Table 5. Recapitulation of Stability Analysis Result With Manual Calculation

No	Conditions	Overturning	Sliding	Foundation Bearing Capacity	
				$\sigma 1$	$\sigma 2$
1	Normal water conditions without sediment	12,080	6,396	6,150	12,700
2	Normal water conditions are full of sediment	11,099	3,840	8,834	12,342
3	Normal water conditions, full of sediment, and earthquakes	6,354	2,197	6,541	14,775
4	Flood conditions without sediment	3,484	2,875	1,286	15,063
5	Flood conditions are full of sediment	3,897	2,085	3,969	14,705
6	Flood conditions, full of sediment, and earthquakes	2,929	1,522	1,284	17,692
7	Wall edge	3,706	2,790	4,766	11,981

Source: Calculation Result (2024)

Table 6. Recapitulation of Stability Analysis Result With Software Plaxis 2D V20.

No	Conditions	Total Displacement (cm)	Safety Factor	Safety Result
1	Empty water surface without earthquakes	0,505	3,876	Safe
2	Empty water surface and earthquakes	1,123	3,638	Safe
3	Normal water conditions without earthquakes	0,238	6,281	Safe
4	Normal water conditions and earthquakes	1,118	3,876	Safe

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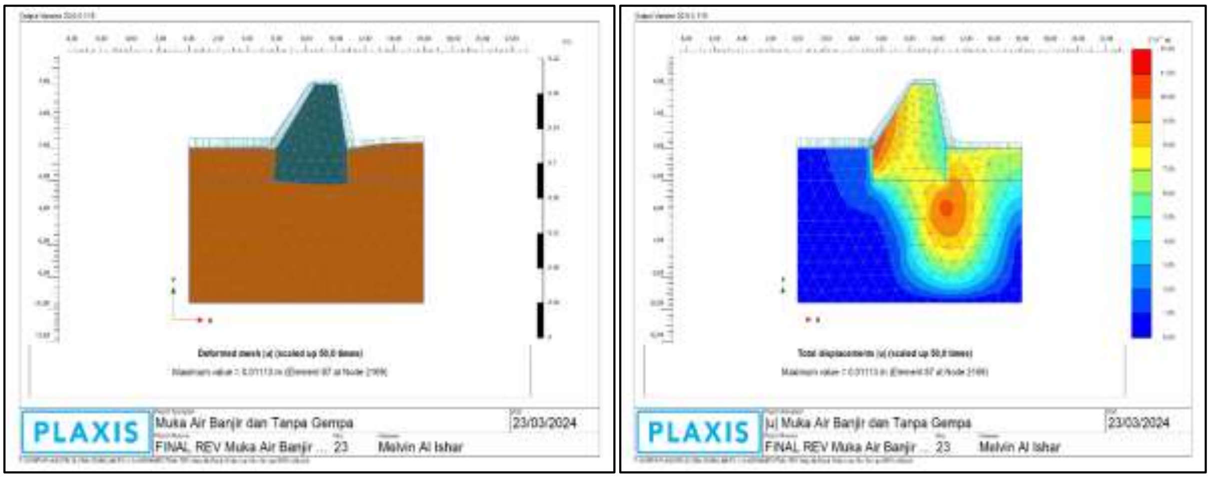
No	Conditions	Total Displacement (cm)	Safety Factor	Safety Result
5	Flood conditions without earthquakes	1,113	1,620	Safe
6	Flood conditions and earthquakes	71,590	1,616	Safe

Source: Output Plaxis (2024).



Source: Output Plaxis (2024).

Figure 5. Deformed Mesh and Total Displacement Result To Flood Conditions Without Earthquakes.

4.7. Budget Plan Development

The details of the work items carried out include cleaning and stripping of soil surface (striping) up to 2 cm diameter plants, slash cut tree/tree trunks diameter > 15-30 cm, slash cut 1 m^2 plants/growth diameter > 5-15 cm, ordinary land excavation > 1-2 m deep, 1 m^3 backfill soil excavation > 0-200 m^3 without compaction (manually), split stone masonry with mortar type M, fc' = 17,2 Mpa semi-mechanical, tire purchase, tire mobilization and demobilization, and tire cutting. From the calculation result, the cost budget plan needed to build a check dam using waste tires is IDR773.472.940. If used tires are obtained for free, it will further reduce the budget.

5. Conclusion and Suggestion

5.1 Conclusion

Based on the results and discussion, conclusions can be drawn:

1. The type of flow is obtained, namely debris flow with a sediment discharge of 25,393 m^3/s which occurs when the 25-year return period.
2. The dimensional parameters of the check dam design results are obtained as follows: water level above the spillway = 2,74 m, main dam height = 4 m, crest width = 1,6 m, stilling basin length = 17,64 m, and sub dam height = 1,75 m.
3. The results of stability analysis using manual numerical methods and Plaxis 2D V20 software, show that the design of the used tire building is safe and has greater strength.
4. The check dam effectively mitigate for approximately 4 days.
5. The cost budget plan required to build is IDR773.472.940 (includes the purchase of tires). So the use of used tires for water-building construction materials can be used as an alternative to reducing the amount of infrastructure financing.

5.2 Suggestion

For further research, more detailed stability analysis is required especially in tires installation considering the critical safety factor of shear calculation. In addition, other methods can be used to determine the discharge of incoming sediment or can be added to the erosion rate analysis. So that the total sediment obtained from erosion and debris flow is obtained in more detail and takes into account the level of erosion hazard, considering the amount of sediment discharge in the result.

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