Analysis of The Stability Plan for Kambaniru Weir, East Sumba District

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Article Information

Manuscript Received 2024-12-14
Manuscript Revised 2024-12-29
Manuscript Accepted 2024-12-29
Manuscript Online 2024-12-31

ABSTRACT

The importance of detailed analysis and calculation in weir construction cannot be overstated, as these processes are critical to ensuring the safety, stability, and long-term effectiveness of hydraulic infrastructures. Thorough analysis helps predict and mitigate various risks arising from natural conditions and operational loads that dams endure. Furthermore, stability calculations are crucial for determining the thickness, materials, and foundation design of dams. These calculations are aimed at resisting hydrostatic and hydrodynamic pressures, as well as other loads such as soil pressure, seismic forces due to earthquakes, and thermal stresses, ensuring the weir can withstand these diverse challenges. This study aims to analyze the stability plan for the Kambaniru Weir in East Sumba District, focusing on its ability to endure and function under various hydrological and seismic conditions. The research will evaluate how the dam's design can handle the dynamic pressures of water flow, seasonal variations, potential seismic activities, and environmental impacts, thus ensuring both functional efficiency and structural integrity. The research was conducted at the Kambaniru Weir site, utilizing a combination of field observations for data collection and theoretical calculations. The methodology involved collecting technical data on the weir's design and conducting soil mechanics tests to evaluate the dam's stability under normal and extreme conditions. Analysis was performed using relevant engineering formulas and simulation tools to assess the resilience of the weir structure against hydrostatic forces, earthquake-induced stresses, and potential uplift pressures. The study found that the Kambaniru Dam's design effectively meets the stability requirements under various testing scenarios. The technical data and simulations revealed that the weir could handle significant hydrostatic pressures during flood conditions and maintain structural integrity during seismic events. The calculations of forces acting on the weir under different conditions showed that the weir is capable of withstanding substantial uplift pressures and mud compressive forces, confirming the adequacy of the current design and the effectiveness of the proposed stability enhancements.

Keywords: Weir, Stability Analysis, Seismic Resilience, Hydrostatic Pressures, Uplift Pressures, Earthquake

1. INTRODUCTION

In-depth analysis and calculations in weir construction are critical to ensuring the long-term safety, stability and effectiveness of the hydraulic infrastructure. The importance of this analysis lies in its ability to predict and overcome various risks that can arise from natural conditions and operational loads experienced by the dam. Apart from that, calculating structural stability is very important, especially in determining the thickness, material and design of the weir foundation. This aims to withstand hydrostatic pressure, hydrodynamics, and other loads such as ground pressure, seismic pressure due to earthquakes, and pressure from temperature changes that may occur throughout the year. The design and stability of weirs have long been subjects of considerable research within the civil engineering community, particularly given the critical role these structures play in water resource management and flood control. Previous studies have often focused on the hydrodynamic behavior of weirs under various operational and environmental conditions to ensure their safety and functionality. Johnson et al. emphasized the need for comprehensive structural analysis to evaluate weir stability against hydrostatic and hydrodynamic pressures, which are pivotal in the design and maintenance of such infrastructures [1]. Similarly, the impact of sedimentation on weir functionality, noting that sediment build-up can significantly affect the hydraulic efficiency of a weir [2].

Hydraulic performance and the resilience of weirs against natural disasters, particularly earthquakes, have been widely discussed. For instance, the seismic performance of weirs, suggesting that earthquake-induced forces must be carefully considered in the design phase to enhance the structural safety of weirs [3]. This is supported, who developed models to predict and mitigate potential damages caused by seismic activities [4], [5]. In areas prone to high seismic activity, such as the Kambaniru region, these considerations are especially pertinent.

The importance of incorporating environmental factors into the stability planning of weirs has also been highlighted in recent studies. The changing climate patterns have direct impacts on the hydrological regimes affecting weirs, necessitating adaptive design strategies to cope with increased flood risks [6]. Furthermore, The examined the effects of water chemistry on material degradation in weirs, proposing new materials that resist wear and enhance longevity [7], [8].

Technological advancements have introduced sophisticated methods for assessing and enhancing weir stability. Simulation techniques using computational fluid dynamics were explored, providing insights into flow characteristics and pressure distributions that are crucial for stability analysis [9], [10]. Moreover, the integration of remote sensing data for real-time monitoring of weirs was examined, offering a novel approach to maintenance and safety evaluations [11].

The ecological impacts of weirs have not been overlooked; The ecological disruptions caused by weirs, urging for eco-friendly design modifications to minimize these effects [12]. This is particularly important for projects like the Kambaniru Dam, which serves agricultural and ecological functions in a biodiverse region.

The long-term sustainability of weirs under changing hydrological conditions has been a focus of several studies. The strategies for ensuring the sustainability of weirs under the threat of increasing variability in river flows and reservoir sedimentation [13]. Such strategies are critical for maintaining the functional and structural integrity of weirs over time.

In response to these diverse challenges, The multidisciplinary approach to weir design, incorporating insights from hydrology, geotechnical engineering, and environmental science to create more robust and resilient weir structures [14]. The application of risk management frameworks in weir stability planning, as discussed by Turner, further supports this comprehensive approach [15].

Recent studies have also explored the economic aspects of weir construction and maintenance. The cost-effectiveness of various weir designs and materials which is crucial for budget-conscious projects [16]. Meanwhile, the potential for using recycled materials in weir construction to reduce costs and environmental impacts [17].

Infrastructure development is one of the massive works carried out by the government at this time. A weir is a building built across a river to raise the river water level and weir the river flow so that the river flow can be tapped and channeled by gravity to areas that need it[18].

Kambaniru Weir is one of the sources of water conservation in East Sumba to overcome drought. The climate in East Sumba has a longer dry season than the rainy season, where the average annual rainfall is quite low, around 800 mm. The Kambaniru Weir was built and designed with the aim of irrigating the rice fields of the surrounding residents, namely Mauliru, Kawangu and Kambaniru. Kambaniru Weir was also established on September 18 1992. Kambaniru Weir is the largest weir in East Sumba which irrigates almost 1,440 hectares of rice fields. An area of 1,000 hectares is allocated for rice fields and the rest is used for secondary crops. Kambaniru Dam, which was built in the 90s, suffered serious damage due to the Hurricane Seroja disaster in April 2021.

To prevent problems from occurring due to damage to the Kambaniru weir, it is necessary to carry out regular field inspections at the Kambaniru weir and observe problems for repairs so that the weir can function well because it has a safe and stable structural plan[19].

The construction of the Kambaniru Weir has great benefits, but on the other hand there are various potential disasters that could cause material losses and casualties. The construction of new dams must follow the principles of the weir safety concept. The first pillar is structural safety, which includes security against structural failure, hydraulics and seepage. The second pillar includes routine operation, maintenance and monitoring to ensure the weir continues to function optimally. The third pillar is emergency preparedness, which aims to prepare quick handling steps if an emergency situation occurs, so as to minimize risks and adverse impacts [20].

Stability is one of the requirements that must be met in the construction of a weir, where if the stability requirements are not met, it will result in weir safety problems which include settlement, leaks, seepage, landslides, erosion and cracks. This stability is influenced by many factors, including the material forming the weir body, determining the weir body zone, slope, wave or earthquake load, etc. [21].

The weir that is built must meet stability requirements which are one of the important requirements to ensure the life of the weir and its ability to raise the water level that flows towards agricultural land. Likewise, the Kambaniru Dam, which is located in Kambera District, East Sumba Regency, also has to calculate its stability. The aim of this research is to analyze the stability plan for Kambaniru Dam, East Sumba Regency.

2. RESEARCH SIGNIFICANCE

This research provides vital insights into the structural integrity and operational efficacy of the Kambaniru Weir, which is integral to managing the water resources in an area prone to climatic variability and significant seasonal droughts. By focusing on the stability of the weir, the study aims to ensure that this crucial infrastructure can withstand the physical stresses from hydrostatic pressures, seasonal flood conditions, and potential seismic activities, all of which are exacerbated by the geographical and environmental conditions of East Sumba.

3. RESEARCH METHODS

This research was conducted at Kambaniru Weir which is located in the Luku Kambaniru River, East Sumba Regency, East Nusa Tenggara Province. The research location has a river length of around 118 km and covers a river basin (DAS) of 1,540 km². The research method includes several stages, namely the preparation stage which includes literature study to obtain direction and field observations for data collection. Research steps include collecting weir design and technical data as well as soil mechanics data. The data is analyzed using an appropriate formula to evaluate the stability of the weir. The results of this data analysis were then used to prepare a final report examining the performance of Kambaniru Weir stability planning. Research flow chart diagrams are used to describe the data processing process to achieve the desired final results.

The materials used in this research include concrete and steel whose technical specifications comply with international standards for dam construction. Reinforced concrete is used for the pillar and weir body, with appropriate compressive strength calculations to withstand water pressure and hydrostatic loads. Geotechnical materials such as geotextiles are also used to stabilize the soil and reduce the risk of erosion around the weir structure. Documentation of the existence and condition of local geology is also carried out using core drilling and soil sampling, which analyzes the structure of soil and rock at the location to assess potential risks such as liquefaction during an earthquake. Results from laboratory tests on soil and rock samples provide important data regarding the mechanical characteristics and response of materials to applied loads, which is crucial in the design of earthquake-resistant structures.

4. RESULTS AND DISCUSSION

Weir Technical Data

Weir Type

a. Weir Type
b. Mercu weir : Mercu round
c. Lighthouse radius : 0,75 m

Design Data

1. Debit plan (Q100) : 20,30 m3/s
2. Total width of the weir (B) : 69,40 m
3. Effective width (Be)

a. The height of the lighthouse (p) : 7,00 m
b. Kp : 0,01 (rounded pillar ends)
c. Ka : 0,00 (round abutments)
d. High energy above the lighthouse (He) : 4,55 m
e. Number of pillars (n) : 3

Be = B – 2 * (n Kp + Ka) * He
= 69,40 – 2 * (3* 0,01 + 0,00) * 4,55
= 69,13 m

4. High guard (w) : 0,50 m
5. Elevation of the Lighthouse : +16.40
6. Elevation of the stilling pool bottom : + 7,00
7. Elevation of upstream M.A : + 20,30
8. Elevation of downstream M.A : + 14,04

Design of the Kambaniru Weir Mercu

4.1 Stability Analysis

Analysis of the stability of the Kambaniru Weir is seen from two conditions, namely when the water level is normal, including earthquakes and without earthquakes, and flood water levels, including earthquakes and without earthquakes.

Forces Acting on Weirs.

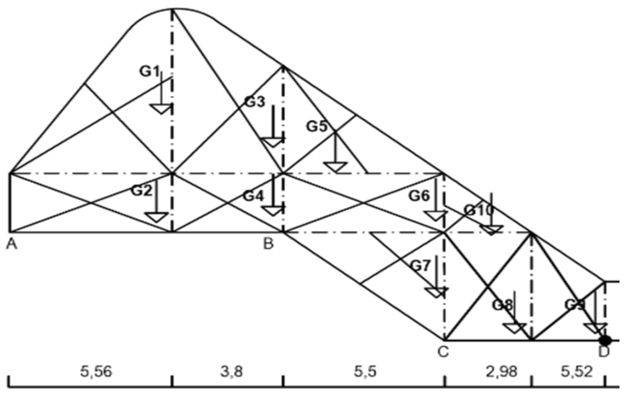

Fig. 1 Forces that act on the weir

Fig. 1 shows that the type of force G1 has the largest area, namely 19.43 and produces the largest moment in the table, namely 786.216, with a vertical force of 46.632 and a moment arm length of 16.86 meters. This shows that objects with larger areas tend to produce larger moments if the length of the moment arm is also significant. On the other hand, G9, which has the smallest area (5.79) and a very short moment arm length (1.62 meters), produces the smallest moment, namely 22.512.

The pattern that can be drawn from this data is that an increase in area and constant specific gravity at a certain level supports an increase in vertical force, but the resulting moment is strongly influenced by the length of the moment arm. Objects with longer moment arm lengths tend to have a greater influence on the total moment produced, as seen in objects G1 and G2 compared to objects G8 and G9.

4.2 Earthquake Effects

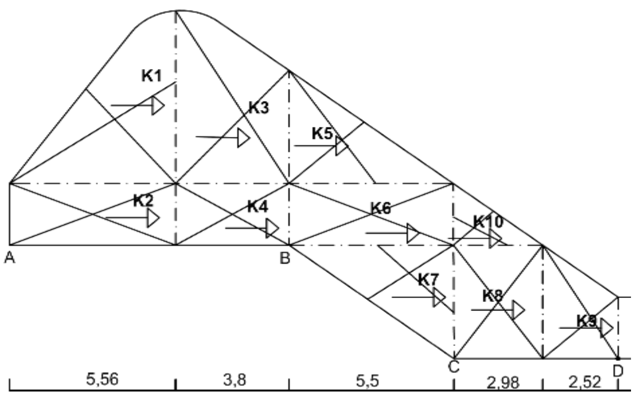

Fig. 2 Earthquake-induced forces acting on the weir

Fig. 2 shows the influence of earthquake forces on overturning moments on various objects identified from K1 to K10. This table calculates the resulting earthquake force by multiplying the constant earthquake coefficient (E = 0.1786) by the gravity of each object, then multiplying the result by the length of the moment arm to produce the overturning moment.

This analysis shows that object K1, which has the largest gravity (46,632) produces the highest overturning moment in the table, namely 140,399. This occurs due to a combination of large gravity and a fairly long moment arm (16.86 meters). In contrast, object K9, which has the lowest gravity (13.896) and the shortest moment arm length (1.62 meters), produces the smallest overturning moment, namely 4.020.

The overall calculation results for earthquake force reached 48,747, with a total overturning moment reaching 516,420. This shows that there is a strong correlation between gravity, earthquake coefficient, and moment arm length in determining the magnitude of the resulting overturning moment. Objects with greater gravity and longer moment arms contribute significantly more to the total overturning moment, indicating the importance of considering these factors in structural design against earthquake loading.

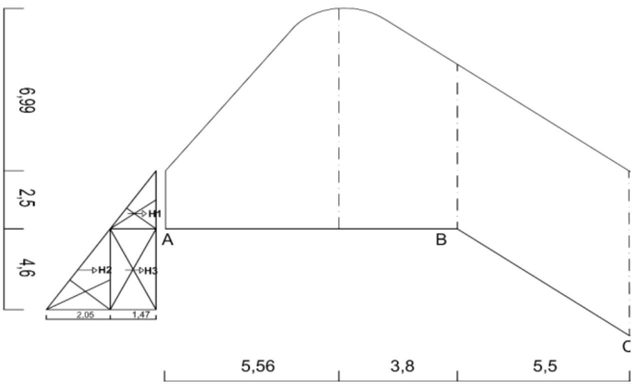

Fig. 3 Hydrostatic Force Under Normal Water Conditions

Fig. 3 shows that object H3 has the highest moment of resistance, namely 14,631 ton.m. This is caused by a combination of a larger area (3.48 m²), a larger hydrostatic force (5.116 tons), and a fairly long moment arm (2.86 m). This shows that a large holding moment depends on a large surface area and a long moment arm, which increases the effect of hydrostatic forces.

On the other hand, object H2, despite having a larger surface area than H1, produces a lower holding moment (6.813 ton.m) because it has a shorter moment arm (1.91 m), emphasizing the importance of the moment arm in generating the moment. which is significant.

Flood Water Conditions

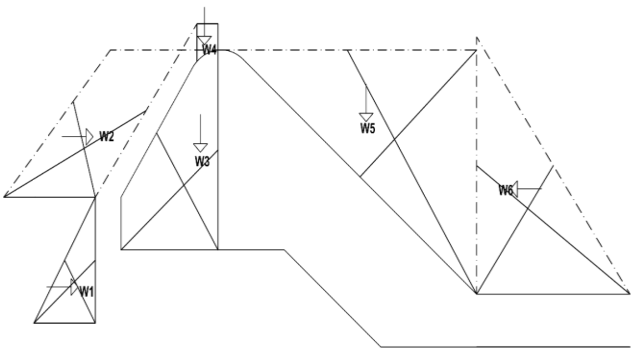

Fig. 4 Hydrostatic force in flood water conditions

Fig. 4 shows that W5, with the largest area (90.55 m²) and very high hydrostatic force (90,550 tonnes), produces the largest resistance moment among the entities considered, namely 425,586 tonnes.m. The relatively short moment arm length (4.7 m) in W5 shows that the area and high hydrostatic forces are very dominant in producing large moments, even though the moment arm is shorter compared to several other entities.

Meanwhile, W6 also shows significant torque, at 656,298 ton.m, which is the highest in this table. This is caused by a combination of high hydrostatic force (53.707 tons) and a fairly long moment arm length (12.22 m), confirming that the moment arm length plays an important role in increasing the resulting resistance moment.

On the other hand, W4, with the smallest area (1.5 m²) and minimal hydrostatic force (1,500 tons), recorded the lowest moment of resistance, namely 23,130 ton.m, despite having a long moment arm (15.42 m). This indicates that the area and hydrostatic force have a greater influence than the length of the moment arm in producing high moments.

4.3 Lifting Force (Uplift Pressure)

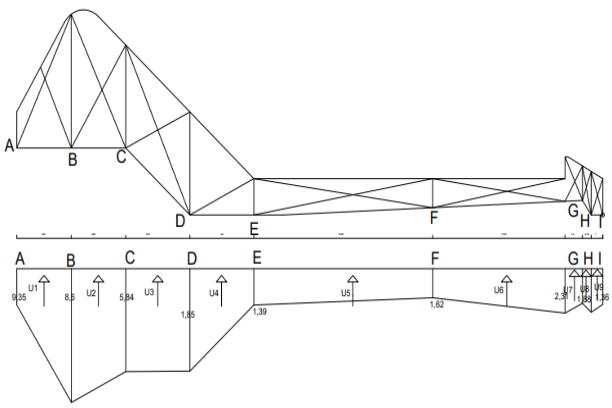

Fig. 5 Up lift force acting on the weir under normal water conditions

Fig. 5 shows that points D, E, H, and I, which have a watershed height (Hx) of 14.1, show very high Px values, ranging between 13,328 and 13,541. This indicates that the hydrostatic pressure increases significantly at points where the boundary water height is greater. For example, points D and E, which have the lowest observed water height (Lx) in this group, record the highest pressure. This shows that the lower the observed water level relative to the boundary water level, the higher the resulting pressure, due to the higher water column above the measurement point.

In contrast, point C, despite having the same boundary water height as points A and B, recorded a higher pressure (7.101) because it had a lower observed water height (5.84). This shows that hydrostatic pressure is also affected by the observed water height, not just by changes in absolute water height.

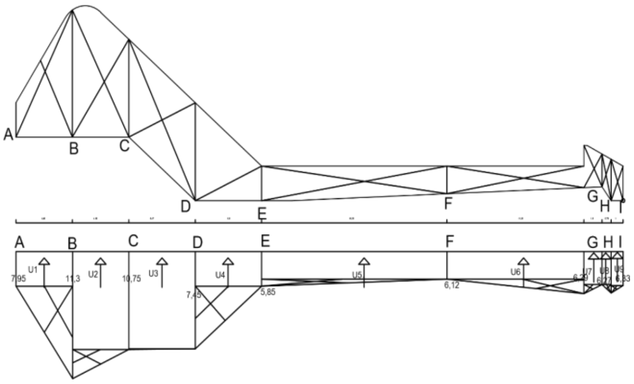

Fig. 6 Uplift force acting on the weir in flood water conditions

Fig. 6 shows that U1, with the largest area (15.75 m²) and significant uplift force (15.745 kN), produces the largest moment among all entities, namely 125.173 kN. This confirms that entities with larger areas tend to experience larger uplift forces, which in turn lead to higher moments, especially when combined with a relatively large moment arm length (7.95 m).
On the other hand, entities with much smaller areas such as U8 and U9, which have areas of only 0.02 m² and 0.27 m² respectively, produce very small moments, namely 0.146 kN and 1.709 kN. This shows that although the length of their moment arms is quite significant, the small area produces minimal uplift forces, thus having a low impact on the resulting moments.
An entity such as U2, which has the longest moment arm in this table (11.3 m), but a relatively smaller area (4.94 m²) than U1, can still produce a significant moment of 55.817 kN, demonstrating the importance of length. moment arm in its influence on the resulting moment.

4.4 Mud Pressure Force

Fig. 7 shows that Ps 1 and Ps 2 have an area of 19.43 m² and 19.05 m² respectively with consistent soil activity coefficients and mud specific gravity of 1 and 1.6 tons/m³. Ps 1 produces a force of 31,092 tons and Ps 2 produces a force of 30,476 tons. This large area and high activity coefficient indicate that a sufficiently large area of mud has the potential to exert significant stress on the weir structure. Ps 1, with a moment arm of 9.43 m, produces a moment of 293.19 ton.m, while Ps 2, with a longer moment arm (11.23 m), produces a greater moment, namely 342.25 tons. m.

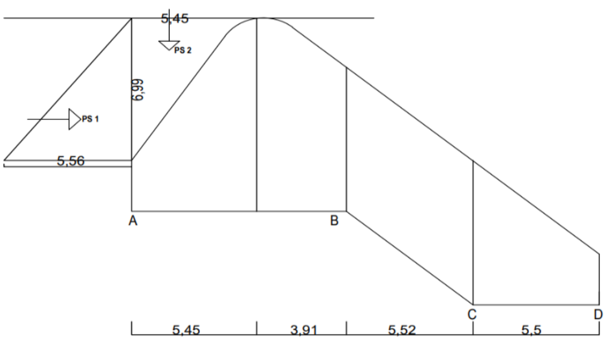

Fig. 7 Mud pressure force on the weir

Fig. 7 shows that the length of the moment arm has a strong influence in increasing the resulting moment; Ps 2, although having a slightly smaller area and slightly lower force than Ps 1, can produce a larger moment due to its longer moment arm.

5. CONCLUSION

1. The design of the Kambaniru weir, including the height and width of the lighthouse as well as the energy height above the lighthouse, affects its effectiveness and stability in managing water flow and the load it receives. The effective width of the beacon has been calculated to ensure optimal performance under varying operational conditions.
2. Under normal water and flood conditions, the surface area exposed to water plays an important role in determining the magnitude of hydrostatic and uplift forces. For example, in flood conditions, points W5 and W6 indicate significant moments generated by the combination of a large area and an effective moment arm.
3. Analysis of the forces induced by the earthquake shows that the combination of gravity and moment arm length significantly determines the resulting overturning moment. This is important in antisismic design of weirs to ensure that the structure is resistant to earthquake loads.
4. The forces and moments generated by mud pressure show that larger areas and long moment arms effectively increase the generated moments, which shows the importance of considering potential mud pressure in weir design and maintenance.

6. ACKNOWLEDGEMENTS

All authors would like to thank Tribhuwana Tunggadewi University, Indonesia so that the research could be carried out well.

7. AUTHOR CONTRIBUTIONS

All the authors have been contributed equally to finish this work.

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