Landslide Mitigation Strategies in Riverbank Areas: A Step-by-Step Guide to Design Retaining Wall

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Abstract. Landslide mitigation in riverbank areas is crucial to prevent erosion and ensure the stability of the riverbanks, which are often subject to water flow pressures and changes in soil moisture. Landslides in riverbank areas can pose significant risks to communities, infrastructure, and the environment. Effective mitigation strategies are essential to prevent or minimize these hazards. Some common approaches are vegetation management, early warning systems, community based approaches, and engineering solutions. This paper focuses on discussing engineering solutions for designing retaining walls to prevent soil landslides in riverbank areas. A step by step guide to design retaining wall consisted of site assessment, determine wall type, and perform engineering calculations. These steps were carried out in a case study in Tanjung Karangan village, where there is a steep riverbank. A retaining wall was designed as part of the landslide mitigation measures on the riverbank areas. The design was proposed to the local government for consideration in construction.

Keywords: Landslide, Riverbank, Erosion, Mitigation, Retaining Wall

1 Introduction

Riverbanks, often situated at the interface of terrestrial and aquatic ecosystems, are particularly susceptible to erosion and mass wasting events such as landslides [1]. These areas are frequently subjected to dynamic forces from river currents, which can undermine the stability of the bank and lead to significant land loss. The consequences of riverbank erosion can be severe, including property damage, infrastructure failure, loss of agricultural land, and environmental degradation. Moreover, erosion can exacerbate flooding risks by reducing the capacity of rivers to convey water during high-flow events. Given these risks, implementing effective mitigation measures is crucial to protect communities and infrastructure located near rivers. A comprehensive approach to riverbank erosion management should consider factors such as soil type, vegetation cover, hydrological conditions, and human activities.
Mitigation measures, such as the construction of retaining walls, proper drainage systems, and the use of vegetation to stabilize slopes, are essential in preventing these hazards. Effective mitigation not only protects the physical environment but also preserves the economic and social well-being of communities living near riverbanks. Moreover, controlling erosion and stabilizing slopes help maintain the natural flow of rivers, reducing the risk of flooding in downstream areas. Landslides along riverbanks are a leading cause of infrastructure damage and land loss worldwide, particularly in

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regions with steep topography and high rainfall [2]. Therefore, implementing engineering and natural solutions to mitigate landslides in these areas is crucial for ensuring long-term environmental stability and human safety.

2 Landslide Mitigation Strategies

Landslides in riverbank areas can pose significant risks to communities, infrastructure, and the environment. Effective mitigation strategies are essential to prevent or minimize these hazards. Some common approaches are vegetation management, early warning systems, community based approaches, and engineering solutions.

2.1 Vegetation Management

Landslide mitigation requires a comprehensive understanding of its causes. To obtain analysis results that meet the needs of the field, the understanding of landslide triggering factors must be adapted to the location of the slope such as slope slope, earthquake, vegetation, and climate [3]. The presence of vegetation in a landscape has a positive impact on the balance of the wider ecosystem. In general, the role of vegetation in the ecosystem is related to regulating the balance of carbon dioxide and oxygen in the air, improving the physical, chemical and biological properties of soil, regulating groundwater systems, and others [4]. The presence of vegetation in an area generally has a positive impact, but the effect varies depending on the level of richness and diversity. For example, vegetation around watersheds generally reduces the rate of soil erosion, but how much erosion depends on the diversity and amount of vegetation that makes up the vegetation formation in the area [5]. Plants that grow on the ground have the function of breaking up and absorbing the impact (runoff) on the water surface caused by raindrops and water flow [6]. Vegetation also keep soil and water at minimal or initial levels, thereby increasing productivity in critical areas [7].

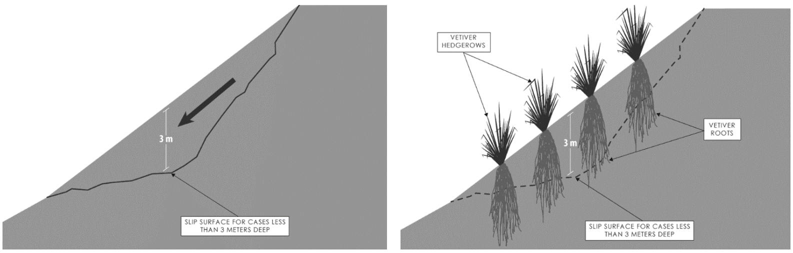

Fig.1 Vetiver Grass to Prevent Landslide (source: https://tvnwi.org/the-vetiver-system/)

Vegetation on the river bank serves to maintain the stability of river banks from the onslaught of water currents, mechanical energy of rain, and infiltration of water into the broken pores of river banks. Branches, twigs, and leaves of plants growing on the riverbank act as a component to dissipate the mechanical energy of water flow and rainwater, and act as a current director and secondary flow director along the river.

Plant roots act as part of the stability of the riverbank and as an ero-sion barrier due to cliff abrasion and surface flow erosion [8]. Land along riverbanks, including the vegetation on them, is lost to the waves, resulting in land-slides and riverbank erosion, as well as other riverbank damage. The type of plants in a location is influenced by soil factors, water flow dynamics, sunlight, tempera-ture and other microclimates, so not all riparian vegetation is suitable for different locations. In general, vegetation is very specific to a particular section of river. Therefore, it is important to find the type of vegetation that is suitable for the area you want to protect.

2.2 Early Warning System

Landslides are categorized as one of the causes of natural disasters, in addition to earthquakes, floods, and hurricanes, among others. Landslides can cause huge losses, including loss of life, property damage, and destruction of natural ecosystems. Landslides often occur during the rainy season, when rainfall intensity reaches 70 to 100 mm per day, or when heavy rain falls for a long period of time and water accumulates in the soil pore structure [9]. The state of the soil body filled with water has an impact on weakening the bond between the soil and the formation of cracks in the soil, and once the saturation point is reached, the soil is no longer able to withstand the weight of water and buildings so that landslides can occur at any time. Landslides cause both direct and indirect damage. Significant direct impacts include loss of life and injury, property loss, and damage to public infrastructure, while indirect impacts include loss of topsoil fertility and reduced agricultural productivity [10]. Therefore, to avoid the occurrence of landslides, efforts are needed that lead to minimizing the consequences (mitigation) that will be caused. One form of mitigation in order to deal with the occurrence of natural disasters and at the same time to reduce the impacts caused by them is the availability of early warning systems, including the availability of data and information on areas vulnerable to landslide hazards.

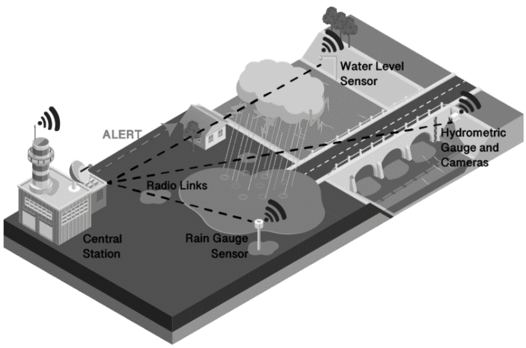

Fig 2. Illustration of Early Warning System For Landslides [11]

Early warning systems for landslides such as the application of geographic information system technology can help mitigate natural disasters by identifying locations and assessing problems related to landslide impacts [12]. Mitigation efforts to reduce or minimize the impact of landslides (mitigation) is done by creating a GIS model, by analyzing several map themes as variables to obtain areas vulnerable to landslide hazards and risks. In addition, satellite images can also be utilized indirectly in determining landslide potential, describing the surface of an area, and geological structures. Another early warning system that is needed is a mitigation or an action to reduce the impact of landslides that can be done structurally by focusing on repairing/strengthening the slope or nonstructurally by focusing on educating the community around the slope. Landslide itself can be caused by several factors, such as slope shape, vegetation, earthquake, and climate on the slope.

2.3 **Community Based Approach**

The importance of public awareness to participate in non-physical disaster management is very necessary. It is necessary for the community to understand how to deal with the risk of landslides to increase their self-efficacy [13]. Self efficacy is an individual's belief in his/her ability to act or control the situation in a disaster event. To deal with disasters that can occur at any time, the community needs to have the capacity and confidence in dealing with landslides through education and socialization [14]. Prior to the socialization and education activities, participants will receive a module containing materials about landslides, landslide preparedness, and self-efficacy. Prior to the implementation of the activity, participants were given a questionnaire to assess their understanding of the material topics to be delivered. The questions given are related to the community's understanding of increasing self efficacy in landslide disaster preparedness. Therefore, the community approach is carried out as a form of community service by providing important information about landslides, the causes of landslides and how to anticipate landslides

2.4 **Engineering Solution**

One of the most commonly used soil reinforcement concepts in civil engineering works is retaining walls, which are constructed to resist soil loads vertically or against a specific slope. Retaining walls are also used to retain or support soil embankments and provide stability to soils or other materials where the mass of material does not have a natural slope [15]. A retaining wall is a structure built to prevent the collapse of land or steep slopes whose stability cannot be guaranteed by the slope of the terrain itself, to maintain topography, and to maintain verticality. Retaining wall buildings are used to resist lateral soil pressure caused by reclaimed soil or unstable native soil. Based on the research on the analysis of retaining wall reinforcement (Case study: Wampu Dam area, Kutaburu District, Karo Regency) the results of the calculation of the stability of the retaining wall under static conditions, the research was carried out on the analysis of retaining wall reinforcement (Case study: Wampu Dam area, Kutaburu District, Karo) resistant to overturning and shear The structure has a stable load capacity. The stability of the retaining wall against rolling, shear and bearing capacity has a safe value of SF> 1.5, SF value (over turning) = 2.331; SF (Sliding) = 2.779; SF (bearingcapacity) = 4.839.The results of the calculation of the stability of the retaining wall under dynamic conditions show that the structure is stable against rolling and load-bearing, but unstable against shear. The stability and bearing capacity of the retaining wall against overturning results in a safety value of or SF > 1.5. SF value (Floating) 1.028 < 1.5; SF value (over turning)) = 1,849. SF (bearingcapacity) = 1.779 When a structure is subjected to earthquake loads, its SF value decreases [16].

3 A Step-by-Step Design of Retaining Wall

To determine the appropriate mitigation for landslides using retaining walls, there are some steps: 1) Conduct a thorough site assessment to understand the soil conditions, slope stability, and potential for landslides. 2) Establish design objectives for the retaining wall, considering factors like stability, drainage, and aesthetics. 3) Select the most suitable wall type based on the site conditions and design objectives. 4) Choose appropriate materials for the wall and drainage system. 5) Design the foundation to ensure adequate stability. 6) Implement the construction of the retaining wall, including excavation, foundation installation, wall construction, and backfilling.

3.1 Site Assessment

Field survey is a very important early stage in the planning and implementation process of a construction project. At this stage, a series of test is carried out. There are topography test and geotechnical tests. Topographic measurements are made of the land surface to be reviewed. The purpose of a topographic survey is to collect the data needed to create a topographic map. The map image of the merged data will form a topographic map. Topographic maps show the character of vegetation by using the same symbols as the horizontal distance between certain features and the elevation of each above specific data. Topographic surveys aim to obtain information about the ground surface at the project site. This information can include various things, such as height, physical condition, and position of natural and man-made objects. In this process, geospatial methods are used to facilitate the reception of topographic information. The information generated from these measurements includes contour maps, elevation maps, and maps of other natural features related to the construction site. In addition, topographic data also plays an important role in determining the direction and pattern of drainage, which affects the design of the retaining wall. With a clear understanding of the topographic conditions of the site, planners can ensure that the design not only suits the land conditions, but also considers mitigating the risks of flooding, erosion and other geotechnical disturbances that may occur during and after construction. This method is used to obtain information on changes in elevation or topography of an area, which is very important in development and disaster mitigation projects. And the soil investigation provides a comprehensive understanding of the geotechnical conditions at the project site, minimizing the risk of structural failure. The soil test in the field that was used to obtain soil shear strength consist of deep boring, standard penetration test, cone penetration test, vane shear test, pressuremeter test, etc. These soil test will provide soil parameter such as soil type, ground water level, cohesion and internal friction angle of the soil. These soil parameter can be used to analyze geotechnical problem in the field.

3.2 Determine Wall Type

Retaining walls are generally classified based on their shape, characteristics, design criteria, and applications. The selection of a retaining wall type is typically based on the topographic and geological conditions of the construction site, working conditions, the purpose of the wall, and the height of the wall. Generally, retaining walls are placed at the foot of problematic areas or potential slope failure. Common types of retaining walls used for riverbanks, such as: gravity wall, cantilever wall, gabion wall, and sheetpile wall. Gravity walls rely on their own weight for stability. They are typically constructed of concrete, masonry, or stone. Cantilevel walls have a base that extends into the ground, providing stability. They are often made of reinforced concrete. Gabion walls are constructed using wire baskets filled with rocks. They are often used for erosion control and can be aesthetically pleasing. Sheetpile walls are driven into the ground and is effective for soft soils or areas with high water tables.

3.3 Perform Engineering Calculations

To perform engineering calculations for a retaining wall design, the process involves a series of steps and analyses to ensure stability, safety, and functionality. A guide that outlines the key stages in the design of a retaining wall consisted of loading calculation and stability analysis. There are three kind of loading working in a retaining wall, they are lateral earth pressure, surcharge load, and hydrostatic pressure. Use Rankine or Coulomb theory to calculate the lateral earth pressure acting on the wall. Active pressure acts when the wall moves away from the soil. Passive pressure acts when the wall moves into the soil. If additional loads (e.g., buildings, vehicles) are applied on the surface behind the wall, they must be included in the earth pressure calculations. Consider if there is water behind the wall, as it adds significant pressure. In stability analysis, ensure the wall satisfies three major stability requirements. They are overturning: the wall should not rotate under the influence of the earth pressure. Calculate the resisting moment (from the weight of the wall and soil) and the overturning moment (from the lateral earth pressure), sliding: The wall must resist sliding due to lateral pressure. Friction between the base of the wall and the foundation soil contributes to sliding resistance, and bearing capacity: the foundation of the wall must be stable, meaning it should not sink or fail under the weight of the wall and soil pressure. Factor of Safety (FoS) for overturning should generally be around 1.5, The FoS for sliding should generally be around 1.5, and The FoS for bearing capacity should be around 3.0. These can be calculated using seismic coefficients or based on local building codes. In addition to numerical calculations, slope stability analysis can be performed using software such as finite element method programs or limit equilibrium programs [17].

4 Case Study: Riverbank in Tanjung Karangan Village

Tanjung Karangan, one of the districts traversed by the Enim River, presents a unique challenge. Pulau Panggung village, situated along the riverbank, is highly vulnerable to landslides due to the steep incline of the bank, disrupted equilibrium of the supporting and resisting forces, erosion at the base, increased load from expanding settlements, and inadequate drainage. The potential for significant damage from landslides underscores the urgent need for infrastructure development. Retaining walls are a viable solution to mitigate riverbank erosion. To ensure the successful construction of these structures, thorough research and planning are essential. The existing condition of riverbanks has a slope angle of approximately 20 degrees.

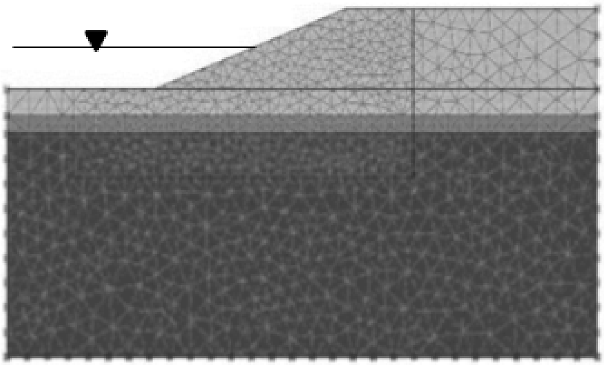

Fig 3. Existing Condition of Riverbank

Existing condition of riverbank was modeled by a finite element program. The result of program showed that existing condition of riverbank has safety factor less than 1,5. The current condition of the riverbank is not safe if rain occurs, which may cause slope failure [18]. As discussed before, the first stage of designing a retaining wall is determination of soil stratification. To obtain soil profile of location, soil investigation should be conducted. The point of soil investigation can be on the top of slope and on the tip of slope. Then, the second stage is determination of wall type. This stage should concern about material and installation of wall. Generally, sheetpile wall was common type for riverbank areas. Sheetpile was modeled into finite element program to show the global stability of retaining wall. If the result of running shows the safety factor less than 1,5, the design of sheetpile should be re-analysis. Retaining wall design calculations can also be performed numerically by initially determining the loads acting on the wall [19]. Subsequently, the stability against overturning, sliding, and bearing failure is assessed. Provided that all stability criteria are satisfied, the design can proceed to implementation at the riverbank.

5 Conclusion

Riverbanks are highly vulnerable to erosion and landslides, which can lead to serious consequences such as property damage, land loss, and increased flood risks. Effective mitigation strategies are essential, including vegetation management to reinforce the soil, early warning systems to detect landslide risks, and community engagement to enhance disaster preparedness. One of the primary solutions is constructing retaining walls to maintain soil stability. Proper design and planning are crucial, as demonstrated in a case study in Tanjung Karangan, where retaining walls were used to prevent landslides caused by riverbank erosion. Implementing these measures helps minimize damage and ensures better environmental safety.

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