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IDENTIFICATION OF LANDSLIDE HAZARD IN RESIDENTIAL AREA KUBANG TANGAH DISTRICT, SAWAHLUNTO

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ABSTRACT
The residential area in Kubang Tangah, Sawahlunto, is an area that has the potential for significant landslide hazard. With rapid residential growth and environmental change, risks to the security and well-being of residents are becoming increasingly prominent. This research aims to identify factors that trigger landslide hazard and analyze potential risks in the residential context of Kubang Tangah. Analysis of regional geotechnical and topographic characteristics, land use modeling, and review of the impact of human activities on slope stability. The analysis method uses the Plaxis 2D program to obtain slope safety factors in the Kubang Tangah residential area, Sawahlunto. The research results show that residential areas in Kubang Tangah have a high level of landslide risk, influenced by slope, soil type, and changes in land use. Varying rainfall levels significantly contribute to the potential for landslide hazard. Mitigation recommendations are suggested to involve wise land use changes, strengthening infrastructure, and increasing public awareness of the dangers of landslides.
Keywords : *Landslide, Residential, Kubang Tangah*

1. Introduction

Residential in various regions often face significant risks from natural hazards, one of the most severe threats being landslides. Various factors, including geological conditions, extreme rainfall, changes in land use, and unsustainable human activities, can cause landslides (Crozier, 1986; Cruden & Varnes, 1996). Residential in areas prone to landslides pose a severe risk to the lives and property of residents. Residential on mountain slopes or areas with significant land slopes have a high risk of landslides. Geological characteristics, such as soil type, rock structure, and slope stability, can influence landslides potential. Extreme rainfall often triggers landslides (Guzzetti et al., 2008; Baum & Godt, 2010; Segoni et al., 2014; Roccati et al., 2019). Areas with high levels of rainfall are at greater risk, especially if the soil becomes saturated. Climate change patterns that result in unpredictable rainfall intensity can increase this risk. Human activities, such as deforestation, intensive agriculture, or infrastructure development, can damage soil layers and reduce their resistance to landslides (Andriani et al., 2023).

Kubang Tangah, Sawahlunto, is an area with rich natural potential but also faces the risk of natural hazards, especially landslides (Hakam & Istijono, 2016). Rapidly expanding human settlements in this region indicate challenges related to disaster resilience, especially landslides, which require in-depth understanding and appropriate preventive measures. Kubang Tanah is located in an area that may have specific geological characteristics that influence slope stability. The varied topography in this area can be an essential factor in determining the level of landslide risk. Rapid land use changes, such as deforestation, uncontrolled agriculture, or infrastructure development, can reduce the resilience of slopes and increase the potential for landslides. Unplanned settlement growth can trigger this danger. Areas that have high rainfall can trigger landslides, especially if the ground becomes saturated with water. Climate change patterns and rainfall intensification may be additional risk factors. Landslides not only pose a threat to physical infrastructure but can potentially cause severe social and economic impacts. Property loss, loss of resources, and threats to public safety must be considered.

A landslide in Kubang Tangah Village, Lembah Segar District, Sawahlunto, caused transportation access to be cut off (02 April 2023); landslide material covered the road and caused people's houses to be affected by the danger of landslides. Figure 1 shows several landslide incidents in the Kubang Tangah area, Sawahlunto.

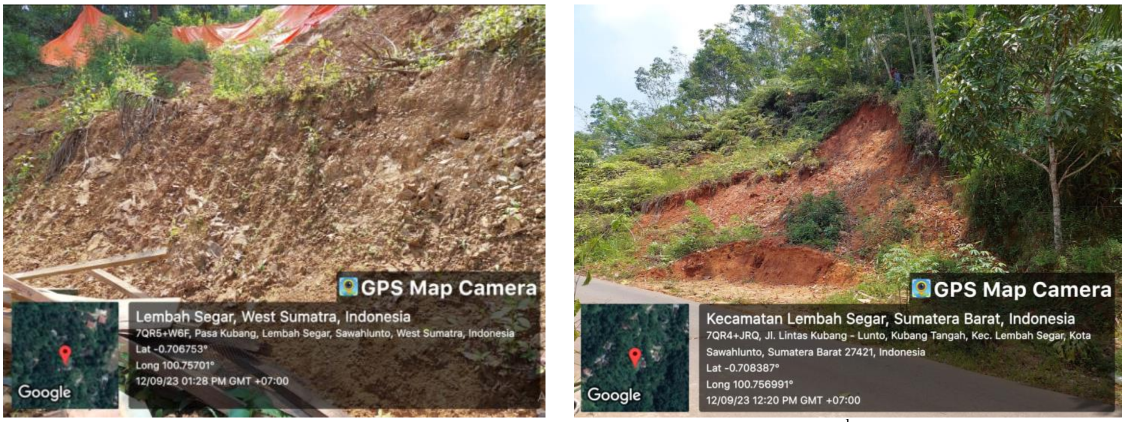

Fig. 1. Landslide in Kubang Tangah Village, Sawahlunto (April 2nd, 2023).

The Kubang Tangah village area and its surroundings are part of the slopes of the Batang Ombilin River valley with moderate to rather steep slopes (15^o - 50^o) and elevations ranging from 250 - 400 meters above sea level, and the dominant rock type is clay shale with moderately weathered conditions - strong which is impermeable so it tends to hold water. Clay shale rocks can become slip surfaces from ground movement in high rainfall. The stability of the slope will be disturbed due to imbalances caused by natural activities, for example, erosion, high rainfall, tectonic movements, etc., so that the material that forms the slope tends to slip due to its own weight and external forces resisted by the shear strength of the soil material. Disturbances to stability occur when the shear resistance of the soil cannot compensate for the forces that cause sliding in the landslide area. Figure 2 shows the relationship between soil shear strength and slip surface. If there is a critical combination of normal and shear stress, failure will occur.

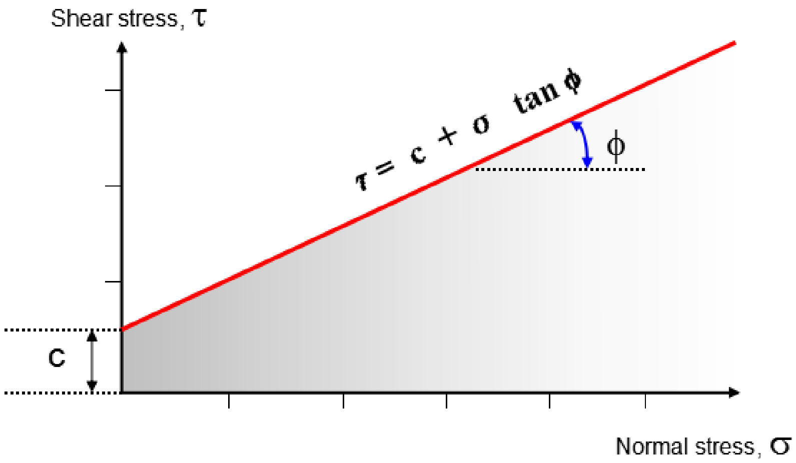

Fig. 2. Relationship between soil shear strength and failure.

Apart from the above, unplanned land use changes can increase the risk of landslides (Istijono et al., 2016). Increasing population growth and uncontrolled residential development often exacerbate the risk of landslides. Settlements that do not pay attention to security aspects and risk mitigation can increase vulnerability to landslides. Landslides impact physical infrastructure and have significant social and economic consequences. Loss of life, property damage, and community isolation can place a heavy burden on affected communities (Andriani et al., 2023). In this context, research on landslide hazards in the Kubang Tangah residential area, Sawahlunto, is significant for identifying influencing factors, measuring risk, and designing effective mitigation strategies. Many factors cause landslides. This research analyzed slope safety factors in the Kubang Tangah residential area using the Plaxis 2D Program. Plaxis is a software that can help analyze slope stability to determine safety factors (SF) based on soil conditions, slope geometry, and seismic or rainfall factors. Modeling with various scenarios and different soil conditions can be carried out using Plaxis, making it possible to identify landslides and choose the appropriate repair method, such as retaining walls. The analysis was carried out by considering the influence of soil type, slope geometry, soil saturation conditions, and loading on landslide potential in the Kubang Tangah residential area, Sawahlunto.

2. Research Methods

The research was conducted in Kubang Tangah Village, Sawahlunto, West Sumatra's residential areas. In general, settlements are located in areas with a slope of > 30^{o}. Figure 3 shows the layout of residential conditions in Kubang Tangah village, Sawahlunto.

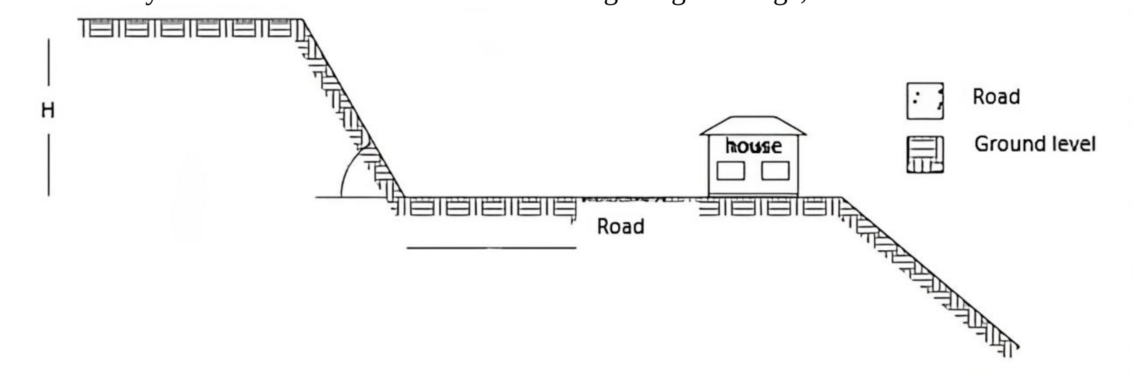

Fig. 3. Settlement conditions in Kubang Tangah Village, Sawahlunto.

Slope stability depends on the driving and resisting forces acting on the slip surface. Resisting force is the force that prevents landslides from occurring while driving force is the force that causes landslides to occur. The ratio between the resisting forces and the forces that move the soil is called the Safety Factor (SF) of the slope. If the pushing force exceeds the resisting force, slope failure will occur (SF < 1). Systematically, the safety factor for a slope can be written using the following formula:

SF > 1.0: The slope is in stable condition.
SF < 1.0: Unstable slope.
SF = 1.0: Slope is in critical condition.

Considering the many factors that influence the level of stability of mining slopes, the analysis results with FK = 1.00 cannot guarantee that the slope is stable. This is because several factors need to be considered in the slope safety factor analysis; thus, a minimum safety factor value with a specific value is recommended as the lowest safety factor limit that is still safe so that the slope can be declared stable. So, in this research, the minimum safety factor used is (SNI 8460, 2017):

SF ≥ 1.25 : Stable slope.
SF = 1.07 – 1.25 : Unstable slope.
SF < 1.07 : Critical slope.

Slope stability analysis was carried out using the Plaxis program. This research consists of two stages, namely:

a. Stage 1: Field observations, data collection, and soil sampling
b. Stage 2: Analysis of slope stability using the Plaxis program.

Stage 1

The collected supporting data in the form of photos of landslide events longitudinal and cross sections of slope geometry that describe the shape of the landslide area. Undisturbed soil samples were taken at three landslide points, and then the soil shear strength was tested in the laboratory. Soil samples were taken at the slope's top, middle, and bottom. Soil data required includes wet volume weight (γ), cohesion (c), location of the groundwater table, and internal friction angle (φ). Slope geometry measurements are carried out to determine the slope height (H) and slope slope (^{o}). Figure 4 shows soil sampling in the field.

Fig. 4. Sampling of undisturbed soil at the landslide location.

Stage 2

Slope stability analysis using the Plaxis program application. Plaxis can carry out modeling in three dimensions (3D), making the data obtained more detailed and accurate. Plaxis also provides visualization tools in the form of animations and graphics, making it easier to understand soil behavior better and helping interpret analysis results. Modeling groundwater movement, infiltration, and changes in soil conditions caused by water is essential to evaluate slope stability. Soil data and slope geometry are analyzed based on the work stage. The stages of work carried out are as follows:

a. The first stage, Plaxis Input: modeling of the original slope stability conditions according to conditions in the field (geometry model, soil data, structural loads, general meshing, initial conditions)
b. The second stage, the Plaxis Calculation program, is used after the input process for the work we are reviewing has been completed. This program can be automatically opened after selecting the calculate toolbar at the end of the program input. If the calculation is not done directly after the input process, we can open this program by selecting Calculation Program on the start menu. At this stage, slope stability analysis is carried out using the Plaxis application to obtain the original slope's safe value (SF).
c. Stage 3, Plaxis Output Plaxis output can be called by clicking on the Plaxis output toolbar or from the start menu corresponding to the Plaxis 2D program. The Calculation toolbar in the Calculation Program can also be used to enter the program output if the input is complete and the point to be reviewed has been selected. The output is in the form of Safety Factor (SF), the magnitude of the driving moment, the radius or slope failure radius, and the center point of the failure. The results of this output can be used to mitigate landslide disasters in the residential area of Kubang Tangah Village, Sawahlunto.
d. Plaxis Curves. The Plaxis Curves Program can be used to draw load or time relationship curves to displacement stress-stress diagrams from locations previously selected in the Calculation Program (select point for curve). The selection of points is limited to ten nodes and ten stress points.

3. Results and Discussions

Soil Type

One of the internal factors that causes landslides is the type of soil. The soil is divided into fine and coarse textured soil based on its texture. Fine-textured soil has impermeable properties so that water flows slowly into the soil, and this causes water to be stored in soil pores so that soil pore water pressure (u) increases while the effective stress decreases (σ') (Stanchi et al., 2012; Tofani et al., 2017; Aprisal et al., 2019; Marino et al., 2020). When the effective stress value becomes zero, the soil does not have the strength to support its weight, so the slope collapses.

Tables 1 and 2 show the soil testing results at three sampling locations in the Kubang Tangah residential area, Sawahlunto.

Table 1 - Test Results of Soil Type in Kubang Tangah, Sawahlunto.

Location	Soil type	E_{ref} (kN/m^2)	μ	γ (kN/m^2)	γ_{sat} (kN/m^2)	c (kN/m^2)	ϕ(°)
Point 1	Sandy clay	5000	0.2	16.08	17.3	9.8	26.16
Point 2	Sandy clay	5000	0.2	16.56	18.56	10.8	29.31
Point 3	Sandy clay	5000	0.2	15.96	18.64	15.4	26.13

Table 2 - Test Result of Physical Properties and UCST in Kubang Tangah, Sawahlunto.

Location		Water content (%)	Gs	Atterberg Limit (%)			UCST (kg/cm^2)		
				LL	PL	IP	q_u undisturbed	q_u remoulded	ST
Point 1	Top	27.795	2.615	55.99	46.97	9.01	1.189	0.470	2.527
	Toe	35.478	2.665	60.23	45.87	14.87	1.783	0.569	3.136
Point 2	Top	35.922	2.612	52.39	43.45	8.94	1.503	0.709	2.120
	Toe	47.539	2.622	54.67	46.44	8.23	1.678	0.767	2.19
Point 3	Top	30.480	2.612	51.24	39.19	15.05	0.607	0.258	2.351
	Toe	22.510	2.622	48.56	37.28	11.30	0.557	0.258	2.155

Table 1 shows that the type of soil in the Kubang Tangah area is dominated by sandy clay. The nature of clay soil is impermeable, so it tends to hold water. During high rainfall, this soil is vulnerable to landslides because clay-type soil can become a sliding surface. Based on the plasticity index value, the soil in the Kubang Tangah area has a Plasticity Index value of <15%, meaning it has moderate swelling potential. If the soil has an IP > 15%, it has a high potential to expand so that during the dry season, the soil will crack, and if there is high rainfall, the soil will expand because the cracks are filled with water and the potential for landslides to occur (Stanchi et al., 2008; L'Heureux et al., 2014; Fashaho et al., 2020; Noviyanto et al., 2020).

Slope

The results of observations in the field show that, in general, the topography in the Kubang Tangah area consists of a hilly area with a slope > 45°. The slope will become gentler from the middle area to the foot of the landslide. The sloping morphology of the Kubang Tangah area causes the vertical force that pulls the landslide material downwards to become higher, giving rise to landslides with basin characteristics that tend to have large soil mass volumes. Steep slopes have the potential for landslides, especially with unstable slope conditions (Andriani et al., 2022; Latif et al., 2023). Soil stability is inversely proportional to the slope; that is, the greater the slope value of a slope, the smaller the soil stability value (Repadi et al., 2022).

Based on the physical environmental conditions, namely soil type, steep/hilly slopes, and high rainfall, the residential area in Kubang Tanah is prone to landslides. Stability analysis needs to be carried out to determine the necessary mitigation efforts.

Analysis of Landslide Point 1

The results of observations in the field show that the slope of the slope at Point 1 = 60°, the slope height is 9.96 meters and the soil type consists of sandy clay.

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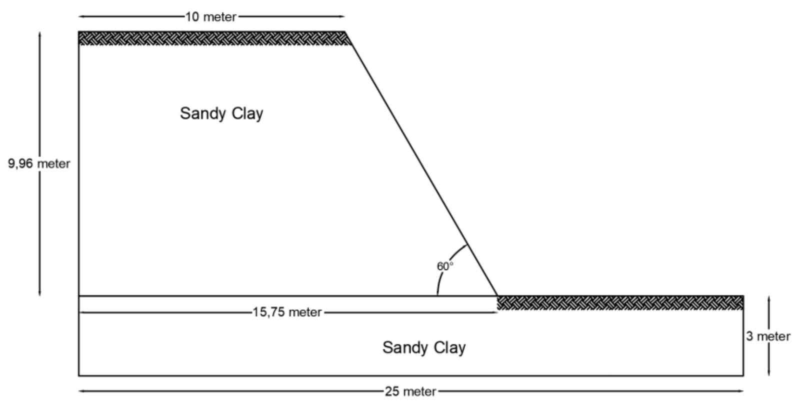
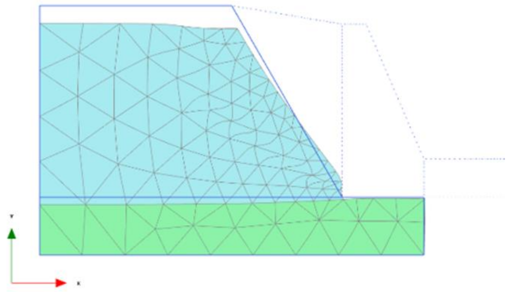
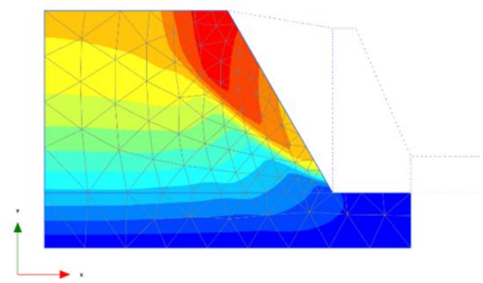


Soil Data :
Soil type: sandy clay
E_{ref} : 5000
V (nu) : 0.2
γ :16.08 kN/m^3
γ_{sat} : 17.3 kN/m^3
slope : 46^o
c : 9.8 kN/m^2
ϕ : 26.16^o



Deformed Mesh (Scale up 0.500x10^{-3} times)



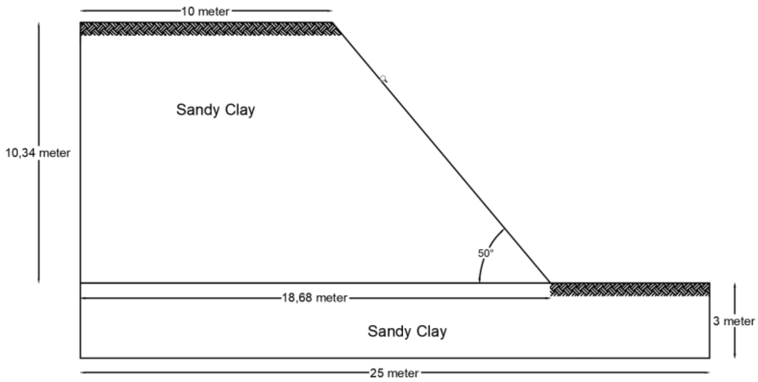
Total Displacement (Scale up 0.500x10^{-3} times)

Fig. 5. Results of slope stability analysis at Point 1.

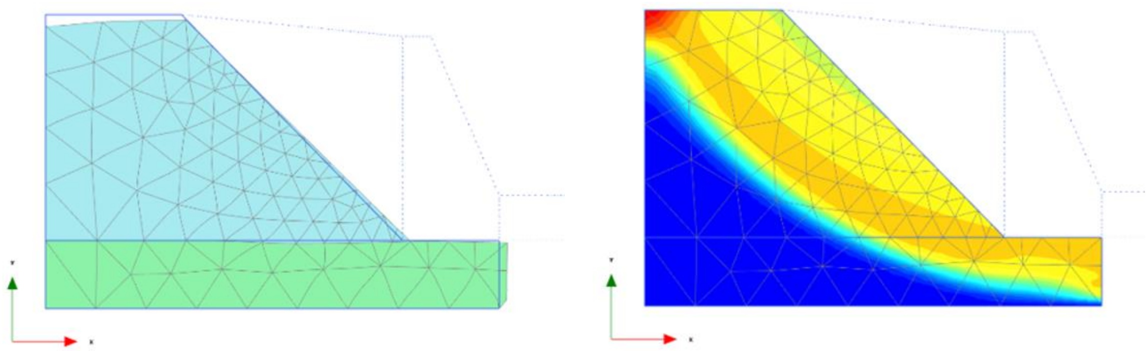
Figure 5 shows the ground movement along the slope; the soil mass experiences movement and collapses. Using the Plaxis application, the slip area that occurs at this point is considered a flat area, obtaining a Safety Factor value of SF= 0.994372 < 1.25, meaning that the slope at point 1 has collapsed. To prevent landslides at point 1, a retaining wall can be used. In this condition, the slope has experienced collapse; it is shown that there is an increase in stress (red), which causes the slope to become unstable/collapse.

Analysis of Landslide at Point 2

The results of observations in the field show that the slope at Point 2 = 46^o, the slope height is 10.34 meters, and the soil type consists of sandy clay. Using flat plane analysis in the Plaxis program, the value obtained is SF = 1.103 < 1.25 (unstable slope). Figure 6 shows the results of slope stability analysis using 2D plaxis, showing the stresses acting due to overburden stress.



Soil Data :
Soil type: sandy clay
E_{ref} : 5000
V (nu) : 0.2
γ : 16.56 kN/m^3
γ_{sat} : 18.56 kN/m^3
slope : 46^o
c : 10.8 kN/m^2
ϕ : 29.31^o



Deformed Mesh (Scale up 0.500x10^{-3} times) Total Displacement (Scale up 0.500x10^{-3} times)

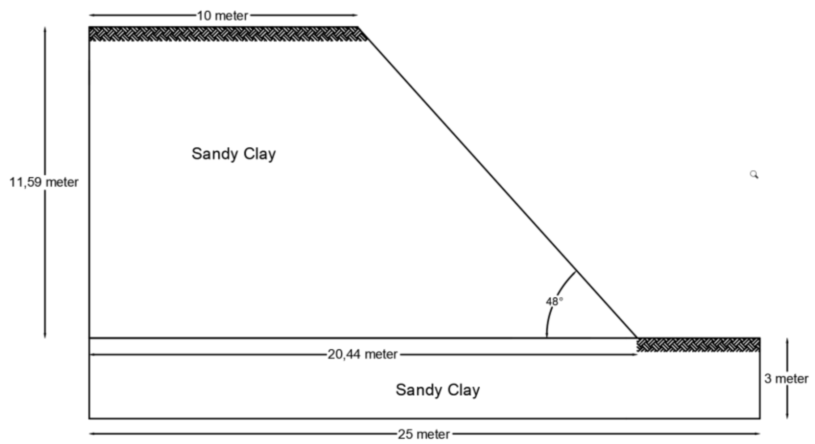
Fig. 6. Results of slope stability analysis at Point 2.

Figure 6 shows the ground movement along the slope; the soil mass experiences movement and will collapse. By using the Plaxis application, the slip area that occurs at this point is considered a flat area, obtaining a Safety Factor value of SF= 1.03 < 1.25, meaning that the slope at point 2 is in critical condition, the addition/disruption of external stress causes the slope to collapse. Figure 6 shows an increase in stress on the surface, which has not caused the slope to collapse, but additional external load can cause the slope to collapse.

Analysis of Landslide at Point 3

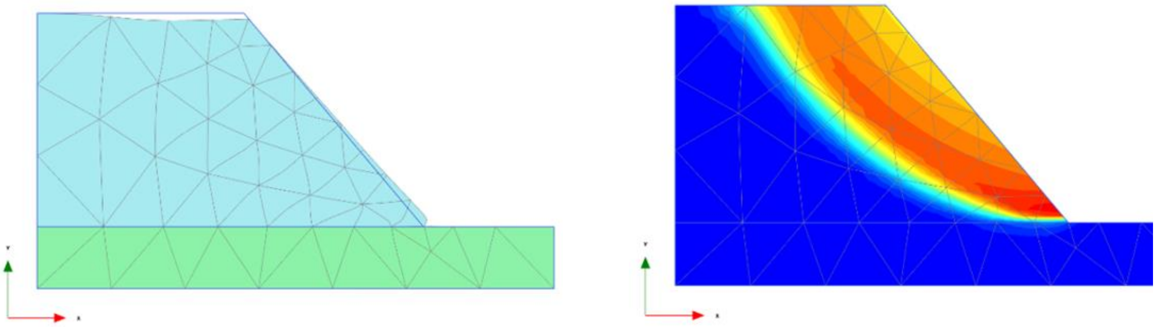
At Point 3, the soil consists of sandy clay, and field measurements show that the slope at Point 3 = 50^{o}, and the slope height is 11.59 meters. Using flat plane analysis in the Plaxis program, the value obtained is SF = 1.194 < 1.25 (unstable slope). Figure 7 shows the results of slope stability analysis using Plaxis, showing the stresses acting due to overburden stress. The stress in the soil will increase if there is high rainfall over a long period because the soil that makes up it consists of clay, which is impermeable so during rain, the granular cavities will be filled with water so that the pore water pressure increases, while the effective stress will decrease.

By using landslide plane analysis in the form of a flat plane, the safety factor (SF) values obtained at Points 1, 2, and 3 have SF values < 1.25 (unstable slopes), so repairs need to be carried out using retaining walls.



Soil Data :

Soil type: sandy clay
E_{ref} : 5000
V (nu) : 0.2
γ : 15.96 kN/m^3
γ_{sat} : 18.64 kN/m^3
slope : 50^o
c : 15.4 kN/m^2
ϕ : 26.13^o



Deformed Mesh (Scale up 0.500x10^{-3} times) Total Displacement (Scale up 0.500x10-3 times)

Fig. 7. Results of slope stability analysis at Point 3.

Slope Stability with Retaining Walls

Slope stability is one of the critical aspects in geotechnical engineering, especially in areas with contoured topography and soil that tends to be unstable. The analysis results show several residential areas in Kubang Tangah, Sawahlunto, are vulnerable to landslide hazards (SF < 1.25). Therefore, retaining walls are commonly used to overcome landslide hazards and maintain slope stability. Retaining walls not only aim to support slope stability but can also create more efficient spatial planning space (Bari et al., 2022). Figure 8 shows the types of retaining walls.

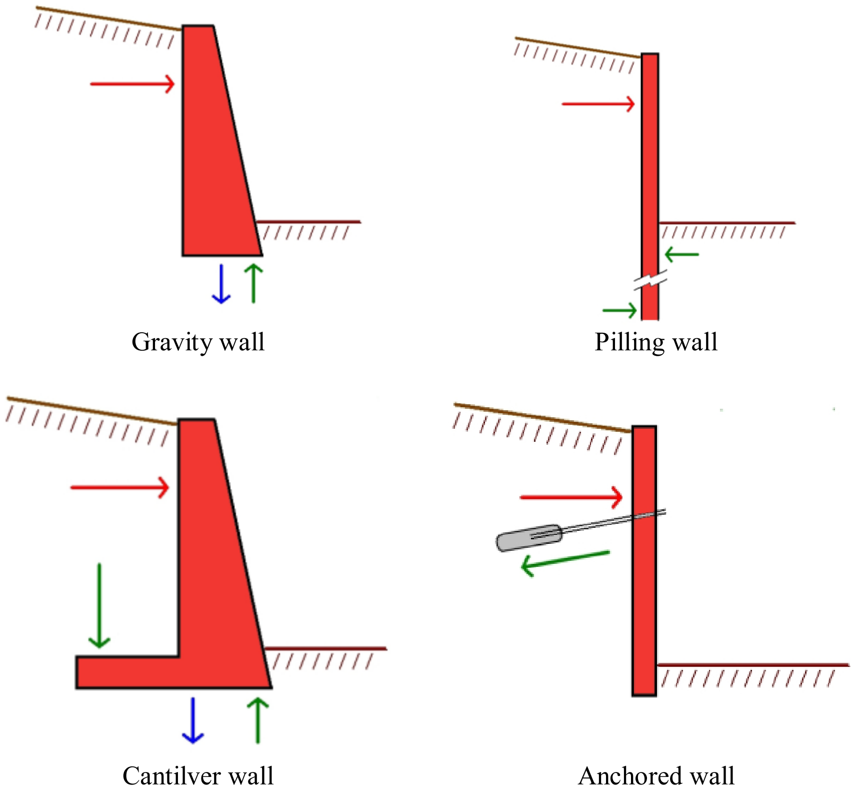


Fig. 8. Types of Retaining Walls

In this study, a gravity wall was used. This retaining wall utilizes the weight and inertia of the construction material as a method to resist lateral pressure from the soil behind it (Bari et al., 2021). The shape can be a vertical wall, a sloping wall, or a combination of both. Construction materials commonly used for gravity retaining walls include ordinary concrete, reinforced concrete, stone, or heavy concrete blocks (Hanafi et al., 2020). The height of the retaining wall used in the research was 5 meters. At the front of the retaining wall, fill was placed to increase the load on the toe of the wall so that it was safe from sliding or overturning.

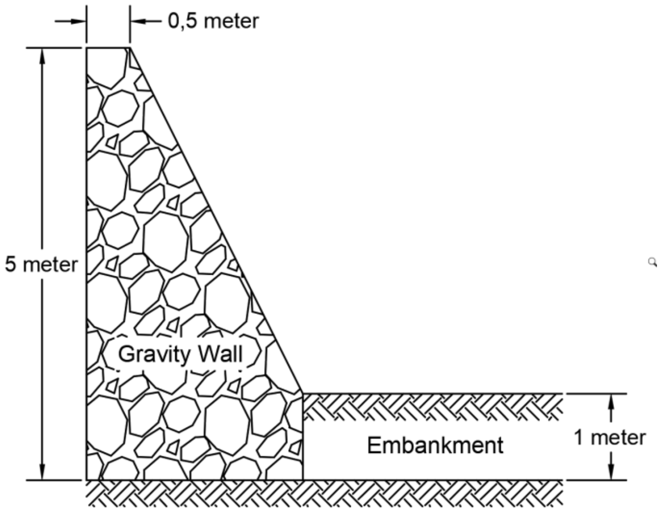


Fig. 9. Design of Gravity Wall for Settlements in Kubang Tangah, Sawahlunto.

Using the Plaxis Program, a gravity wall stability analysis was conducted at 3 locations in the Kubang Tangah residential area, Sawahlunto. Table 3 shows the results of slope stability analysis with and without reinforcement.

Table 3 - Results of slope stability analysis, without and with retaining wall reinforcement.

Location	Soil Type	Slope (^{o})	SF	Stability	Retaining wall and embankment	Δp (kN/m^2)	SF
Point 1	Sandy clay	60^o	0.994	unstable	Active	50	1.635 (ok)
Point 2	Sandy clay	46^o	1.103	unstable	Active	55	1.994 (ok)
Point 3	Sandy clay	50^o	1.194	unstable	Active	45	2.126 (ok)

Table 3 shows that the three slopes studied have SF values < 1.25, meaning that the residential area is on an unstable slope. There has been a collapse on slope one because the SF value is < 1. The low SF value is caused by the type of soil that makes up the Kubang Tangah area consisting of clay, where the nature of clay has a low shear strength value and is impermeable. High rainfall will cause water to enter the soil pores and cause the pore water pressure value to increase so that the bonds between soil grains will weaken as the effective soil stress value decreases. The collapse will occur if the effective stress value (σ') = 0 because there are no bonds between soil grains. Slope conditions also affect slope stability; the steeper the slope, the greater the potential for landslides due to the increasing stress that the soil must withstand.

Retaining walls and embankments at the foot of the slope are added so that the slope can withstand loads (assumed) on a particular scale. The analysis results show that using gravity-type retaining walls makes the slopes safe against landslides (SF>1.25).

The research results show that Kubang Tangah residential area is dominated by clay soil with a small amount of sand content. Geotechnical analysis shows that soil type tends to experience landslides, especially on steep slopes. Areas with a slope > 45^O have a significant risk of landslides (SF < 1.2), so retaining walls are needed to overcome landslides. Using retaining walls is an example of technical mitigation to prevent landslides. Meanwhile, non-technical landslide mitigation involves an approach that considers social, economic, and environmental factors.

4. Conclusion

The Kubang Tangah residential area has a significant potential risk of landslides, influenced by geological characteristics, slope topography, and rainfall patterns. The slope degree is > 30^o, and the type of clay soil is the main factor influencing slope stability. Unplanned land use can increase vulnerability to landslides. The results of the safety factor analysis show that several parts of the slopes in the Kubang Tangah area tend to be unstable (SF<1.25), indicating a potential risk of landslides.

Retaining walls are an alternative that can be used to reduce the danger of landslides in the Kubang Tangah residential area, Sawahlunto. The choice of retaining wall depends on the potential for danger, availability of materials, ease of implementation in the field, and available costs.

Conducting in-depth geotechnical study regarding the main factors causing landslides in the Kubang Tangah residential area is necessary. Spatial modeling in the form of mapping potential landslide disaster areas is essential to help stakeholders identify areas most vulnerable to landslides, develop early warning systems to notify residents about potential landslides, and collaborate between geotechnical experts, environmental experts, social experts, and the government's local to develop holistic and sustainable landslide mitigation solutions. By understanding the characteristics and risks of landslides in the Kubang Tangah residential area, appropriate mitigation measures can be implemented to protect the safety and welfare of the community.

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