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Laboratory Study of Geotechnical Characteristics of Soil in Landslide-Prone Zone in Talamau District, West Pasaman Regency

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Abstract: The main triggering factor for landslides is high rainfall intensity, especially during the rainy season. Excessive rainfall can cause an increase in water content in the soil, which in turn will reduce the shear strength of the soil and increase the volume weight of the soil. The method used is a laboratory experiment by taking samples from the field. The sample of this study was sandy clay soil taken from a landslide-prone area located in Talamau District, West Pasaman Regency. Based on the results of soil geotechnical laboratory tests in the landslide-prone zone in Talamau District, West Pasaman Regency, it can be concluded that the soil sample has moderate plasticity characteristics with a Liquid Limit of 59.39%, Plastic Limit of 49.77%, and Plasticity Index of 9.62%. The soil reaches a maximum dry density of 1.37 gr/cm³ at an optimum water content of 500 ml, with a grain size distribution dominated by the sand fraction (83.978% retained on sieve No. 4-20) and a very low fine material content (1.234%). The results of the triaxial test showed soil behavior that varied from brittle to strain-hardening depending on the level of cell stress. Overall, the soil can be classified as well-graded sand with good drainage but low cohesion, thus requiring additional stabilization for construction applications in landslide-prone areas.

Keywords: Laboratory study; Landslide prone; West Pasaman

Introduction

Indonesia is an archipelagic country with diverse topographic conditions, ranging from lowlands to mountains with steep slopes (Centeno, 2024). These geographical conditions, combined with a tropical climate with high rainfall, make Indonesia one of the countries prone to landslides (Heo et al., 2024; Rakuasa et al., 2025). The landslide phenomenon not only threatens the safety of people's lives and property, but also causes significant economic losses and infrastructure damage that can hamper regional development (Kumar, 2024).

West Sumatra, as one of the provinces with hilly and mountainous topography, faces serious challenges related to the threat of landslides (Kausarian et al., 2024). West Pasaman Regency, located in the northern part of West Sumatra, has geographical characteristics dominated by hills with varying slope gradients (Usman & Sumantyo, 2022). This condition is exacerbated by high tectonic activity due to its position in the Indo-Australian and Eurasian subduction zones, increasing the potential for slope instability in the region (Hutchings & Mooney, 2021).

Talamau District is one of the districts in West Pasaman Regency that has a relatively high level of

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landslide vulnerability (Bari et al., 2023). This area is characterized by undulating to hilly topography with fairly steep slopes, especially in areas bordering rivers (Bian et al., 2025). Local geological conditions dominated by sedimentary and volcanic rocks that have undergone intensive weathering form residual soil with complex and varied geotechnical characteristics (Islam et al., 2024).

The main triggering factor for landslides in Talamau District is high rainfall intensity, especially during the rainy season (Guzzetti et al., 2022). Excessive rainfall can cause an increase in water content in the soil, which in turn will reduce the shear strength of the soil and increase the volume weight of the soil (Das et al., 2022). These conditions, combined with unstable slope geometry, create conditions conducive to landslides (McColl, 2022). In addition, human activities such as land clearing for agriculture, infrastructure development, and mining that do not pay attention to slope stability aspects also contribute to increasing the risk of landslides (Alcantara-Ayala, 2025).

A deep understanding of the geotechnical characteristics of soil is the main key in efforts to mitigate landslide disaster risks (Bilal et al., 2025). Geotechnical characteristics of soil include various parameters such as physical properties, mechanical properties, and soil behavior to changes in environmental conditions (Momeni et al., 2022). These parameters include grain size distribution, Atterberg limits, specific gravity, water content, shear strength, compressibility, and soil permeability. Each parameter has an important role in determining slope stability and the potential for landslides (Woldesenbet et al., 2023).

Laboratory studies are the most accurate and reliable method for determining the geotechnical characteristics of soil (Jastrzębska, 2021). Through a series of standard and calibrated laboratory tests, precise and reliable geotechnical parameter data can be obtained for slope stability analysis (Innocenti et al., 2023). Laboratory tests relevant to this study include soil physical properties tests such as sieve analysis, liquid limit and plastic limit tests, specific gravity tests, and soil mechanical properties tests such as direct shear strength tests, triaxial tests, and permeability tests (Afolagboye et al., 2021).

Previous studies conducted in various landslide-prone areas in Indonesia have shown that the geotechnical characteristics of soil have high variability, even in a relatively small location (Nguyen et al., 2023). This variability is influenced by factors such as the type of parent rock, weathering level, drainage conditions, and loading history. Therefore, studies of the geotechnical characteristics of soil need to be carried out specifically for each location, taking into account local geological and environmental conditions (Daud et al., 2025).

The results of laboratory studies of soil geotechnical characteristics can be used as a basis for various practical applications in landslide risk mitigation (Pasierb et al., 2019). The geotechnical parameter data obtained can be used for slope stability analysis, design of retaining structures, drainage systems, and safe spatial planning. In addition, understanding the geotechnical characteristics of soil is also important for the development of an effective and accurate landslide early warning system (Lin et al., 2025).

Given the high risk of landslides in Talamau District and the absence of a comprehensive study on the geotechnical characteristics of the soil in the area, this study is very important to conduct. This study is expected to provide a significant contribution to efforts to mitigate the risk of landslides through a better understanding of the geotechnical characteristics of the soil in landslide-prone zones. The results of this study can also be a reference for local governments in planning sustainable and safe development from the risk of landslides (Muhiddin et al., 2021).

This study will focus on the geotechnical characterization of soil through a comprehensive series of laboratory tests, with the goal of obtaining an accurate and reliable geotechnical parameter database. The obtained data will be statistically analyzed to understand the variability and distribution of geotechnical parameters, as well as the relationships between parameters that can affect slope stability. This research is crucial, and its results are expected to provide practical recommendations for landslide risk mitigation and serve as a basis for further research in the field of geotechnics and disaster mitigation.

Method

This study employed a laboratory experiment, taking samples from the field. The samples consisted of sandy loam soil taken from a landslide-prone area in Talamau District, West Pasaman Regency, and their soil properties were tested in the laboratory. Laboratory testing was conducted at the Civil Engineering Geotechnical Laboratory, Universitas Andalas and the Padang Institute of Technology. The specific gravity of the samples in this study can be seen in Table 1.

Table 1. Specific Gravity of Sample

Pycnometer Number			1	2
Weight of empty pycnometer	W1	=	30.87	30.9
Weight of pycnometer + dry soil	W2	=	40.87	40.9
Weight of bare soil	Wt	=	10	10
Weight of pycnometer+water+soil at temperature 20°	W3	=	132.59	132.17
Temperature t °C		=		28
Weight of pycnometer + water at temperature 20°	W4	=	126.45	125.75
W5 = Wt + W4		=	136.45	135.75
Fill the land	W5-W3	=	3.86	3.58
Specific gravity Gs = Wt/ (W5-W3)		=	2.59	2.79
Average specific gravity		=		2.69

Results and Discussion

Atterberg Test

The Atterberg test is a laboratory test to determine the consistency limits of fine-grained soil, especially clay and silt, which consists of liquid limit, plastic limit, and shrinkage limit tests. This test is important for classifying soil and understanding its mechanical properties under various water content conditions (O'Kelly, 2021).

The liquid limit test steps begin with preparing a soil sample that passes sieve No. 40, then mixing it with distilled water until it has a paste-like consistency. The sample is placed in a Casagrande bowl and leveled, then a groove is made in the middle using a groove maker. The bowl is tapped at a speed of 2 taps per second until the groove is closed by 13 mm, and the number of taps and water content are recorded. This process is repeated with variations in water content to obtain a flow curve and determine the liquid limit up to 35 taps.

For the plastic limit test, a soil sample with a water content close to the plastic limit is formed into a small ball, then rolled on a glass plate to form a rod with a diameter of 3 mm. The rolling process is repeated until the rod begins to crack or break, which indicates the plastic limit has been reached. The water content at this condition is recorded as the plastic limit. The plasticity index is then calculated by subtracting the plastic limit from the liquid limit, which provides information about the water content range over which the soil is plastic and can be used for soil classification and geotechnical planning. The Atterberg test results can be seen in table 2.

Table 2. Atterberg Test

Types of Examination			Liquid Limit				Plastic Limit	
Many Punches			35	28	23	11		
Cup Number			AR1	AR2	AR3	AR4	A	L
Weight of cup + wet soil		grams =	11	12.65	13.03	16.06	8.44	8.3
Weight of cup + dry soil		grams =	9.51	10.3	10.6	11.58	6.74	6.7
Water weight	(1-2)	grams =	1.49	2.35	2.43	4.48	1.69	1.6
Cup weight		grams =	6.42	6.06	6.91	6.01	3.41	3.42
Dry soil weight	(2-4)	grams =	3.09	4.24	3.69	5.57	3.33	3.28
Water content	(3:5)x100%		48.22	55.85	65.85	80.43	50.75	48.78
Average (%)		=						49.77

Information : Liquid Limit (LL) = Liquid limit graph equation; LL = y = -27.29 ln(x) + 147.23; LL = 59.39 %; PL = 49.77 %; Pl = LL – PL = 9.62 %; SL = 28.78 %

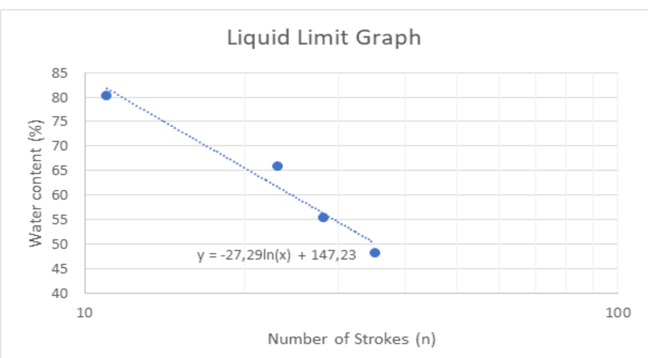

Figure 1. Liquid limit graph

Based on the Atterberg Test data presented, the results of the study indicate the characteristics of soil plasticity that can be categorized as soil with moderate plasticity. The Liquid Limit (LL) value of 59.39% indicates that the soil requires a fairly high water content to reach a liquid state, while the Plastic Limit (PL) of 49.77% indicates the lower limit where the soil can still be formed without cracking. The relatively small difference between these two values results in a Plasticity Index (PI) of 9.62%, indicating a limited range of soil plasticity. The concept of Atterberg limits first introduced by Albert Atterberg in 1911 has become a standard in the characterization of fine-grained soils, and the results of this study are consistent with the basic principles that have been established in the geotechnical literature (Ouyang & Mayne, 2023).

Further analysis of the water content data at various blow rates showed a correlation consistent with the principle of the liquid limit test. At 35 blows, the water content was recorded at 48.22%, then increased gradually to 80.43% at 11 blows. This pattern is in accordance with the theory put forward by Casagrande that the fewer blows required to close the groove, the higher the water content of the soil. The graph equation y = -27.29 ln(x) + 147.23 shows a good logarithmic relationship between the number of blows and the water content, confirming the validity of the test results. Previous studies by various geotechnical experts have shown that this logarithmic relationship is a common characteristic in liquid limit testing, reflecting the rheological properties of clay soils (Carriere et al., 2018).

Based on the USCS (Unified Soil Classification System) classification, soil with a PI between 4-7% is categorized as low plasticity soil, while a PI of 7-17% indicates moderate plasticity. With a PI of 9.62%, this soil sample is included in the moderate plasticity category, indicating that the soil has a moderate ability to deform without losing cohesion. The Shrinkage Limit (SL) value of 28.78% indicates that the soil will experience significant volume shrinkage when the water content decreases below that value. A study conducted by Onyelowe et al. (2022) showed that soils with similar characteristics generally have predictable behavior in engineering applications, although they require special attention to changes in moisture conditions.

Soil with moderate plasticity characteristics requires special attention in construction design. Research conducted by Ahmad et al. (2024) showed that soil with PI in the range of 7-17% is generally suitable for light to medium construction, but requires a good drainage system to prevent volumetric stability problems. The Atterberg limits values obtained also indicate that this soil has a moderate clay mineral content, which is in accordance with the findings of Niu et al. (2024) on the relationship between soil mineralogy and plasticity properties. Soil with similar characteristics can be used as construction materials with appropriate treatment, such as chemical or mechanical stabilization to improve long-term performance.

Compaction

Soil compaction is the process of adding energy to the soil to reduce the volume of air pores, thereby increasing the density and strength of the soil. Water content testing is a fundamental step in compaction because the optimum water content greatly affects the effectiveness of compaction. Water content testing is carried out using the oven method, where wet soil samples are weighed, then dried in an oven at a temperature of 105-110 ° C for 24 hours or until constant weight, then reweighed to calculate the percentage of water content to the dry weight of the soil (Frene et al., 2024).

Compaction checks are carried out to determine the relationship between water content and dry density of soil at certain compaction energies. The testing procedure includes preparing soil samples with varying water content, then each sample is compacted in a cylindrical mold with three or five layers using a pestle with a predetermined weight and drop height. The test results are in the form of a relationship curve between water content and dry density which shows the optimum water content and maximum dry density. Optimum water content is the water content at which the soil reaches maximum dry density with a certain compaction energy, while maximum dry density is the highest density value that can be achieved at that optimum water content (Shimobe et al., 2021). The compaction results can be seen in tables 3 and 4 below.

Table 3. Water Content Check

Sample Number		1		2		3		4		5		6	
Cup Number		A	B	RA1	RA2	RA3	RA4	AR1	AR2	AR3	AR4	D1	D2
Amount of water	ml		200		300		400		500		600		700
Weight of cup + wet soil	gr	33.72	32.55	29.68	33.12	30.69	22.42	25.35	29.18	34.14	34.24	21.53	21.67
Cup weight +dry land	gr	30.29	29.2	25.85	28.79	25.95	19.09	21.02	23.51	26.99	26.63	17.05	16.94
Water weight	gr	3.43	3.35	3.83	4.33	4.74	3.33	4.33	5.67	7.15	7.61	4.48	4.73
Cup weight	gr	5.33	5.42	6.22	6.98	6.66	6.09	6.44	6.07	6.93	6.81	5.91	5.39
Dry soil weight	gr	24.96	23.78	19.63	21.81	19.29	13	14.58	17.44	20.06	19.82	11.55	11.55
Water content	%	13.74	14.09	19.51	19.85	24.57	25.62	29.70	3.51	35.64	38.40	40.22	40.95
Average water content	%		13.91		19.68		25.09		31.10		37.02		40.58

Table 4. Density Check

Mold weight	gr	3380	3380	3380	3380	3380	3380
Weight of mold + wet soil	gr	4740	4805	4905	5010	5075	5040
Wet soil weight	gr	1360	1425	1525	1630	1695	1660
Wet volume weight ($^{\gamma}$b)	gr/cm^3	1.49	1.56	1.67	1.79	1.86	1.82
Dry volume weight ($^{\gamma}$d)	gr/cm^3	1.31	1.31	1.34	1.37	1.36	1.30

Optimum Water Content = Highest value of dry density ($^{\gamma}$d)
= 1.37 gr/cm^3
= 500 ml (seen from the water content used at the highest value $^{\gamma}$d)

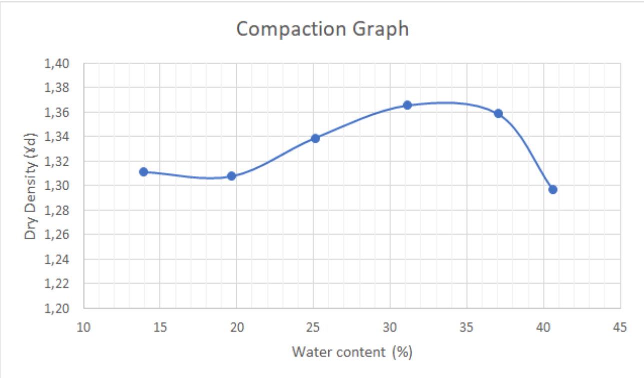

Figure 2. Compaction graph

The results of the water content test showed significant variations along with the addition of water volume from 200 ml to 700 ml. The average water content increased gradually from 13.91% at 200 ml of water addition to 40.58% at 700 ml of water addition. This increasing pattern shows a consistent relationship between the volume of water added and the resulting water content in the soil sample. The variation in water content between samples at each level of water addition was relatively small, indicating consistency in the testing procedure and the homogeneity of the soil samples used.

The density data shows that the wet unit weight (γb) increases with the addition of water, starting from 1.49 gr/cm^3 to a peak of 1.86 gr/cm^3 at 600 ml of water addition, then decreasing to 1.82 gr/cm^3 at 700 ml. This pattern indicates that the addition of water initially helps compaction by lubricating the soil particles, but after reaching the optimum point, the excess water actually reduces the density because it fills the space that should be occupied by solid soil particles. This phenomenon is a normal characteristic in laboratory soil compaction testing.

The test results showed that the maximum dry density (γd) was achieved at a value of 1.37 gr/cm^3 with an optimum water content of around 500 ml. Although there were small fluctuations in the dry density values at various levels of water content (ranging from 1.30-1.37 gr/cm^3), the highest value of 1.37 gr/cm^3 was obtained at optimum water content conditions. This condition indicates the ideal balance point between sufficient water content to facilitate compaction and not excessive so as to reduce the effective density of the soil (Brempong et al., 2023).

These findings have important implications in practical applications of construction and geotechnical engineering. The maximum dry density of 1.37 gr/cm^3 with an optimum water content of 500 ml provides a guideline for achieving optimal soil compaction in the field. The compaction curve formed shows a classic relationship between water content and density, where increasing water content from dry conditions will increase density to a peak, then decrease if the water content is excessive. These data can be used as a reference to determine the appropriate compaction procedure in construction projects to ensure optimal soil stability and bearing capacity (Vitali et al., 2022).

Sieve Analysis

Sieve analysis or sieve analysis is a laboratory test method to determine the particle size distribution of soil based on the percentage of grains by weight that pass through a series of sieves with different hole sizes (Svensson et al., 2022). This test is an important part of soil classification and is used for coarse-grained soils such as gravel and sand. Sieve analysis provides information about soil gradation which is very useful in determining engineering soil properties such as permeability, shear strength, and compressibility (Sohel et al., 2024).

The sieve analysis procedure begins with preparing a representative dry soil sample, then weighing the total weight of the sample. The sample is placed on a sieve stack arranged sequentially from the largest hole at the top to the smallest at the bottom, with a collection pan at the bottom. The sieve stack is then shaken mechanically or manually for a certain time (usually 10-15 minutes) until no more particles pass through. After sieving is complete, the material retained on each sieve is weighed and recorded. The results of the sieve analysis are presented in the form of a grain size distribution curve that describes the relationship between grain size and the percentage of weight that passes through. The results of the sieve analysis can be seen in table 5.

Table 5. Sieve Analysis

Filter number	Filter hole diameter	Weight of soil sieved	% by weight of filtered soil	% cumulative ground sieve	% of soil passing through the sieve
1	2	3	4	5	6
			[(3)/W] x 100		100 – (5)
4	4.75	0	0	0	100
10	2	265.85	53.17	53.17	46.83
20	0.85	154.04	30,808	83,978	16,022
40	0.425	41.35	8.27	92.248	7,752
60	0.25	15.4	3.08	95,328	4,672
140	0.106	10.2	2.04	97,368	2,632
200	0.075	6.99	1,398	98,766	1.234
PAN	-	4.52			
Total weight W1		498.35			

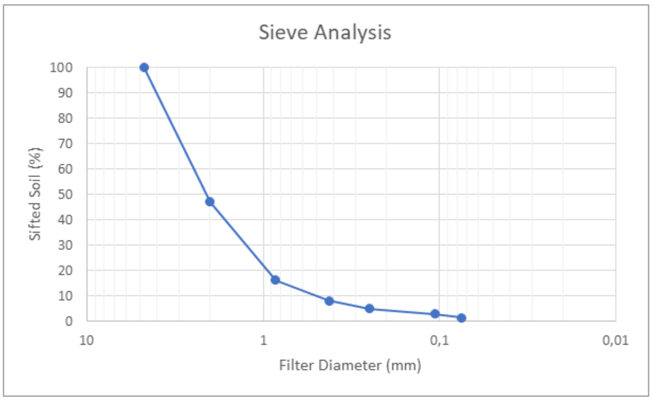

Figure 3. Sieve analysis

The results of the sieve analysis showed that the soil samples had a fairly diverse grain size distribution with a dominance of medium sizes. Of the total sample weight of 498.35 grams, the highest percentage was retained on sieve No. 10 (2 mm diameter) at 53.17%, followed by sieve No. 20 (0.85 mm diameter) at 30.808%. This distribution indicates that most of the soil particles are between 0.85-2 mm in size, which is included in the coarse to medium sand category. The distribution pattern that decreases gradually from large to small grain sizes indicates relatively good gradation, although there is dominance in certain fractions. Sieve analysis determines the particle size distribution of a given soil sample and thus helps in easy identification of the mechanical properties of the soil, which supports the finding that grain distribution characteristics play an important role in determining the engineering properties of the material (Polakowski et al., 2021).

Based on the cumulative percentage passing the sieve, it can be identified that 46.83% of the material passed the No. 10 sieve, 16.022% passed the No. 20 sieve, and only 1.234% passed the No. 200 sieve. This data shows that the fine material (which passed the No. 200 sieve) is very little, which is less than 2%, which classifies this soil as a coarse-grained soil with a very low fines content. Soil gradation is an important aspect of soil mechanics and geotechnical engineering because it is an indicator of other engineering properties such as compressibility, shear strength, and hydraulic conductivity. This characteristic indicates that the soil has relatively high permeability and good drainage, but may have low cohesion due to the minimal content of fine particles such as clay and silt (Shimobe & Spagnoli, 2022).

Based on the obtained grain size distribution, the soil can be classified as well-graded sand according to the soil classification system. Well-graded sand (SW) consists of fine, medium, and coarse grains of sand, which is in accordance with the findings of this study where the material is distributed in a variety of size ranges (Chen et al., 2022). With a dominance of particles measuring 0.85-4.75 mm (83.978% retained on the sieve range Number 4 to Number 20) and a very low fines content (1.234%), this soil has technical characteristics suitable for construction applications that require good drainage such as pavement base layers or filter materials. Good soils are well-graded dense gravel, gravelly sand, silty gravel, excess compacted clay, and rocks, which support the potential application of this material in construction (Wazoh & Mallo, 2021).

Previous studies have shown that soil gradation has a significant effect on the mechanical properties of the material. Test results show that higher shear strength is obtained for gap-graded (GG) soil compared to well-graded (WG) and uniformly graded (UG), although in the context of general construction applications, well-graded sand remains the preferred choice due to its stability. For applications requiring high stability or high bearing capacity, additional stabilization or blending with a binder may be required due to the lack of fine particles that act as natural binders between grains. Fines become significant to the engineering properties and characteristics of the soil when they are contained at least 5% by weight, while the sample in this study only contained 1.234% fines, thus requiring special attention in applications requiring high cohesion (Pande et al., 2020).

Triaxial Testing

Triaxial testing is one of the most important geotechnical testing methods to determine soil shear strength parameters, namely cohesion (c) and internal friction angle (φ) (Ghoreishi et al., 2021). This test is carried out using a triaxial device consisting of a triaxial cell filled with water or pressurized air, where a cylindrical soil sample is placed in a rubber membrane and given cell pressure (confining pressure) from all directions. The main advantage of the triaxial test is its ability to control drainage conditions and measure stress and strain accurately, so that it can simulate stress conditions that occur in the field (Xie et al., 2020).

The triaxial testing procedure begins with the preparation of cylindrical soil samples with a height to diameter ratio of 2:1, then the samples are wrapped with rubber membranes and placed in triaxial cells. The cell pressure is applied gradually while measuring the vertical and horizontal deformation of the sample. Axial loading is applied until the sample fails or reaches a certain strain. The test results are in the form of stress-strain curves and Mohr circles which are used to determine the failure envelope and soil shear strength parameters. This data is very important for slope stability analysis, foundation bearing capacity, and other geotechnical structure designs. The triaxial test results can be seen in table 6 and Mohr Circle Diagrams in table 7.

Table 6. Triaxial Test Data

∑ (%)	Reading Dial	Proving Ring		
		Voltage 0.5	Tension 1	Voltage 1.5
0	0	0	0	0
0.1	7.15	6	3	6
0.2	14.3	10	7	8
0.3	21.45	12	9	10
0.4	28.6	14	10	12
0.5	35.75	16	11	14
1	71.5	25	19	23
1.5	107.25	32	24	30
2.5	178.75	41	31	40
3	214.5	44	35	45
4	286	49	41	51
5	357.5	52	45	57
6	429	54	48	61
7	500.5	54	50	64
8	572	48	51	67
9	643.5	-	49	68
10	715	-	-	64
12	858	-	-	-
14	1001	-	-	-
16	1144	-	-	-
18	1287	-	-	-
20	1430	-	-	-

Table 7. Mohr Circle Diagrams

Mohr Circle Diagrams						Corner
0.5		1		1.5		
x	y	x	y	x	y	
0.5000	0.0000	1.0000	0.0000	1.5000	0.0000	0
0.5600	0.6863	1.0615	0.7035	1.6012	1.1568	10
0.7383	1.3517	1.2443	1.3855	1.9017	2.2784	20
1.0295	1.9760	1.5427	2.0255	2.3925	3.3308	30
1.4246	2.5403	1.9478	2.6040	3.0585	4.2820	40
1.9117	3.0274	2.4471	3.1033	3.8796	5.1031	50
2.4760	3.4225	3.0255	3.5083	4.8308	5.7692	60
3.1003	3.7137	3.6655	3.8067	5.8832	6.2599	70
3.7657	3.8919	4.3476	3.9895	7.0049	6.5605	80
4.4520	3.9520	5.0510	4.0510	8.1617	6.6617	90
5.1382	3.8919	5.7545	3.9895	9.3184	6.5605	100
5.8036	3.7137	6.4366	3.8067	10.4401	6.2599	110
6.4280	3.4225	7.0766	3.5083	11.4925	5.7692	120
6.9923	3.0274	7.6550	3.1033	12.4437	5.1031	130
7.4794	2.5403	8.1543	2.6040	13.2648	4.2820	140
7.8745	1.9760	8.5593	2.0255	13.9308	3.3308	150
8.1656	1.3517	8.8578	1.3855	14.4216	2.2784	160
8.3439	0.6863	9.0405	0.7035	14.7221	1.1568	170
8.4040	0.0000	9.1021	0.0000	14.8233	0.0000	180

The triaxial tests performed demonstrate the application of a well-established methodology standard in geotechnics to determine soil shear strength parameters. Triaxial shear testing is the most versatile of all methods for testing soil shear strength and finding cohesion (c) and angle of internal friction (φ) (Yin et al., 2022). The test data show three different cell stress levels (0.5; 1.0; and 1.5 kg/cm²) with dial and proving ring readings reflecting the soil response to gradually increasing axial loads. A typical triaxial test involves confining a sealed cylindrical soil specimen, with a height-to-diameter ratio of 2:1, into a pressure cell to simulate defined stress conditions. This methodology allows a comprehensive evaluation of the mechanical properties of the soil under controlled conditions.

Based on the data obtained, the stress-strain response pattern shows characteristics that are consistent with the theory of soil mechanics. At a cell stress of 0.5 kg/cm², the sample reaches a maximum value of proving ring 54 at a strain of 6-7%, then decreases to 48 at a strain of 8%. For a cell stress of 1.0 kg/cm², the peak strength is reached at proving ring 51 at a strain of 8%, while at a cell stress of 1.5 kg/cm², the response continues to increase to proving ring 68 at a strain of 9%. The purpose of these procedures is to measure the triaxial shear strength of soil specimens subjected to different drainage conditions in the field. This pattern indicates that the soil exhibits strain-softening behavior at low cell stress and strain-hardening at high cell stress.

The Mohr circle diagram data shows a systematic stress distribution for each cell stress level. The marked values (4.4520; 3.9520) for stress 0.5 and (5.0510; 4.0510) for stress 1.0 probably represent the failure conditions or maximum points in the analysis. The angle α of the considered plane appears as the angle 2 α in the Mohr circle. From the Mohr-Coulomb theory, we can conclude two key things: the Mohr circle represents the stress state in the soil at a point, while the Mohr envelope represents the shear strength of the soil. The x and y coordinates in the table represent the normal and shear stresses which vary with the angle of the failure plane from 0° to 180°.

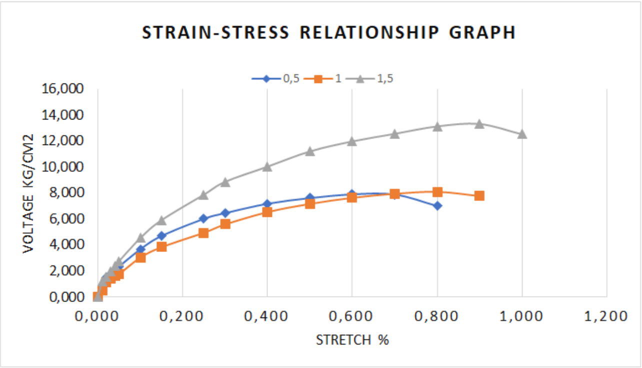

Figure 4. Strain – stress relationship graph

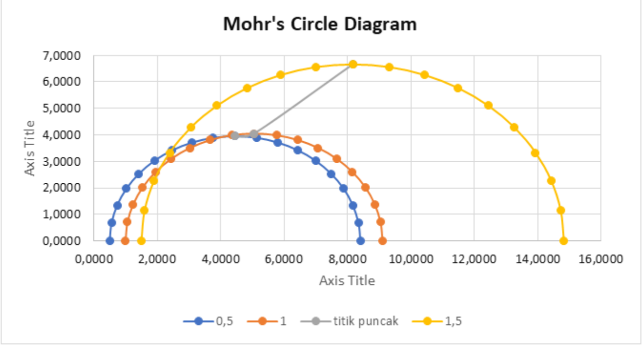

Figure 5. Visual mohr circle diagrams

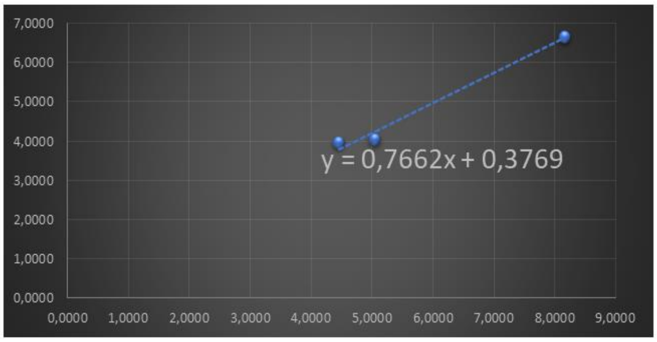

Figure 6. Linear regression graph

Previous studies have confirmed that from triaxial test data, it is possible to extract fundamental material parameters about the sample, including the angle of shear resistance, apparent cohesion, and dilatancy angle (Gong et al., 2020). The results of this test are in line with the principles established in the geotechnical literature. Mohr's circle is used to calculate the angle of soil internal friction and soil shear strength (Rasti et al., 2021). Shear strength is a measure of the resistance of the soil to shift or shear along its plane, where soil with higher shear strength has stronger cohesion between particles. The data obtained allows the determination of the parameters c and φ which are essential for stability analysis and geotechnical design (Doan et al., 2023).

Comparison of soil response at three cell stress levels shows behavior consistent with consolidation and shear strength theory. At a cell stress of 0.5 kg/cm², the soil exhibits brittle behavior with a decrease in strength after reaching a peak. At a cell stress of 1.0 kg/cm², the behavior becomes more ductile with a longer plateau. While at a cell stress of 1.5 kg/cm², the soil exhibits continuous strain-hardening behavior. Mohr's circle is used to determine which principal stresses will produce this combination of shear and normal stresses, and the plane angle at which this will occur. These variations in behavior reflect the influence of effective stress on soil failure mechanisms, which is very important for practical applications in foundation design and slope stability analysis (Chanyshev, 2023).

The results of this triaxial test provide a strong basis for geotechnical design parameters. Triaxial shear test is the most versatile of all shear test methods to obtain soil shear strength i.e. Cohesion (C) and Internal Friction Angle (Ø). The data obtained can be used to determine soil bearing capacity, slope stability, and retaining structure design. The different behavior patterns at each cell stress level indicate the importance of considering in-situ stress conditions in the analysis. The shear strength parameters obtained from this test should be validated with field conditions and used in numerical analysis for prediction of soil behavior on a larger scale (Patil & Pusadkar, 2022).

Conclusion

Based on the results of soil geotechnical laboratory tests in landslide-prone zones in Talamau District, West Pasaman Regency, it can be concluded that the soil sample has moderate plasticity characteristics with a Liquid Limit of 59.39%, Plastic Limit of 49.77%, and Plasticity Index of 9.62%. The soil reaches a maximum dry density of 1.37 gr/cm³ at an optimum water content of 500 ml, with a grain size distribution dominated by the sand fraction (83.978% retained on sieve No. 4-20) and a very low fine material content (1.23%). The triaxial test results show soil behavior that varies from brittle to strain-hardening depending on the level of cell stress. Overall, the soil can be classified as well-graded sand with good drainage but low cohesion, thus requiring additional stabilization for construction applications in landslide-prone areas.

Acknowledgements
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Author Contributions
N: preparation of original draft, results, discussion, methodology, conclusion; F, A. H, B. I, A. S and A: analysis, review, proofreading and editing.

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Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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