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# GEOPHYSICAL AND GEOTECHNICAL STUDY FOR ASSESSING THE POTENTIAL OF LANDSLIDE DISASTERS: A CASE STUDY IN KRUENG SABET, ACEH JAYA, INDONESIA

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**ABSTRACT:** This study investigates landslide susceptibility in the Krueng Sabet Lamno region of Aceh Jaya by integrating geophysical and geotechnical methods, addressing a key gap where these approaches are often applied in isolation. The central hypothesis is that correlating resistivity, seismic refraction, and Cone Penetration Test (CPT) data can more accurately identify weak zones prone to slope failure than single-discipline analyses. Field investigations along the Jantho–Lamno road revealed Silty Sand and Fine Sand layers as potential slip-prone horizons, with CPT data highlighting low-resistance zones and high pore-water vulnerability. Seismic refraction delineated shallow layers, while resistivity models detected low-resistivity anomalies corresponding to water-saturated sediments. From these datasets, three principal subsurface layers were interpreted: Sand and Clay, Weathered Bedrock, and Limestone Boulder. It is emphasized that these interpretations represent subsurface models rather than direct geological confirmation from surface outcrops. Results demonstrate that Silty Sand layers, although overlain by seemingly stable Fine Sands, are critically susceptible under heavy rainfall, groundwater rise, or additional load. The novelty of this study lies in its integrated approach, providing a holistic characterization of slope instability that strengthens disaster mitigation strategies and offers a replicable methodological framework for other landslide-prone regions.

*Keywords: Landslide, Resistivity, Seismic Refraction, Cone Penetration Tests, Krueng Sabet*

## 1. INTRODUCTION

Indonesian archipelago faces frequent seismic events. Aceh Province, located on the northen tip of Sumatra Island, experiences a notable occurrence of earthquakes, particularly during the rainy seasons from September to February. This period of heavy rainfall, as emphasized by [1], accelerates chemical weathering processes, which are thought to degrade rock integrity, thus impacting various engineering properties. Studies by [2,3,4] underscore the detrimental effects of such weathering on the shear strength and stability of rocky slopes. Noteworthy amidst these geological challenges is Krueng Sabet Lamno, characterized by heightened disaster risks.

In terms of disaster mitigation, understanding the geological dynamics and weathering processes in Aceh Province, particularly in areas like Krueng Sabet, Lamno, Aceh Jaya is crucial for implementing effective measures. By comprehending the factors contributing to rock degradation and slope instability, authorities can develop strategies to reinforce infrastructure resilience and improve early warning systems. Additionally, community awareness and preparedness initiatives can be tailored to address the specific risks posed by seismic activity and weathering-induced hazards in these vulnerable regions. The research gap identified in the introduction is the need for an integrated approach involving both geophysical and geotechnical data to comprehensively understand potential landslide hazards in regions like Krueng Sabet. While individual studies may have focused on either geophysical or geotechnical aspects, there is a lack of research that synthesizes these two disciplines to provide a holistic understanding of landslide dynamics. The intricate geological features of this region call for a holistic understanding of both soil and rock characteristics. Therefore, merging geophysical insights with geotechnical data emerges as a crucial methodology. By integrating findings from geophysics [5,6,7] and geotechnics [8,9], we aim to provide more accurate analyses of subsurface conditions. This approach can help pinpoint landslide-prone areas, uncover potential triggers, and enhance disaster mitigation strategies effectively.

Our primary goal is to combine data from these disciplines to gain a comprehensive understanding of subsurface conditions in Krueng Sabet, with a specific focus on landslide precursors. By integrating geophysical and geotechnical insights, we hope to identify vulnerable areas, reveal geological structures contributing to risks, and strengthen our ability to mitigate disasters.

Detecting potential landslides in Krueng Sabet is crucial for protecting the local community and managing disaster risks effectively. Early identification of vulnerable areas allows for proactive measures and minimizes the impact of landslides [10]. Additionally, this effort aids in conserving the natural environment and informs disaster-resilient infrastructure development.

## 2. RESEARCH SIGNIFICANCE

This research holds significance for geotechnical engineering and disaster risk reduction, especially in regions like Aceh Province, Indonesia, with complex geological landscapes. By advancing our understanding of landslide susceptibility along routes like Jantho-Lamno, we can identify weakened layers and potential slip planes, informing targeted protective measures. Moreover, this research informs policy-making, enhances infrastructure resilience, and contributes to global geological hazard assessments. Ultimately, this research not only identifies landslide risks in Krueng Sabet but also provides a blueprint for similar studies in regions with comparable geological features. This localized approach can significantly contribute to disaster prevention efforts and have broader implications for disaster risk management globally.

## 3. DATA AND METHOD

Situated within the Sumatra Fault Zone, the province of Aceh extends from Teluk Semangko to the Andaman Sea. In the province's western region, a subduction zone exists between the Indo-Australian Plate and the Eurasian Plate. The northward movement of the Indo-Australian Plate beneath the Eurasian Plate, with a speed of approximately 5 cm/year, characterizes this subduction [11]. The oblique motion of the Indo-Australian Plate in relation to the trench divides Sumatra Island into two segments along the Sumatra Fault Zone [12,13,14].

Geological Map of the Lamno Regional, Aceh Jaya, is illustrated in Fig. 1. According to the geological map by [15], the Lamno research area in Aceh Jaya showcases diverse formations referred to as the Lhoong Formation (Mulh). Comprising mafic volcanic rocks, limestone, a modest quantity of sandstone, claystone, and shale, the Lhoong Formation has experienced weathering, resulting in clastic sediments deposited within terrestrial environments

Given the intricate geological structures, this research area demands a specialized investigation into slope stability. Analysis of secondary data and pertinent information discloses that the area is prone to frequent high-magnitude earthquakes and intense rainfall, serving as significant factors in triggering potential landslides. Consequently, the implementation of stability and slope protection methods is imperative, even though determining the most suitable method presents challenges for geotechnical engineers. Geological conditions and slope structures emerge as pivotal factors influencing mass movement and the propensity for landslides [16,17 in 18].

The study site is located along the Jantho-Lamno road in Aceh Jaya. The measurement lines extend from southwest to northeast, with lengths of 220 m and 230 m. Along the path, there is a river, and to the south, a mountain exhibits signs of previous landslides, resulting in substantial rock blocks. The measurement site showcases a gently sloping and ascending topography. In the vicinity, there are steep mountain cliffs and deep ravines along the roadside. In the rock landslide area, water accumulates, unable to drain due to the landslide obstruction, leading to water flowing over the road and crossing the river. Adjacent to the river-bordering roadside, there is an apparent water channel eroded by the flow towards the river. The measurements were conducted under overcast to drizzly weather conditions, is illustrated in Fig. 2.

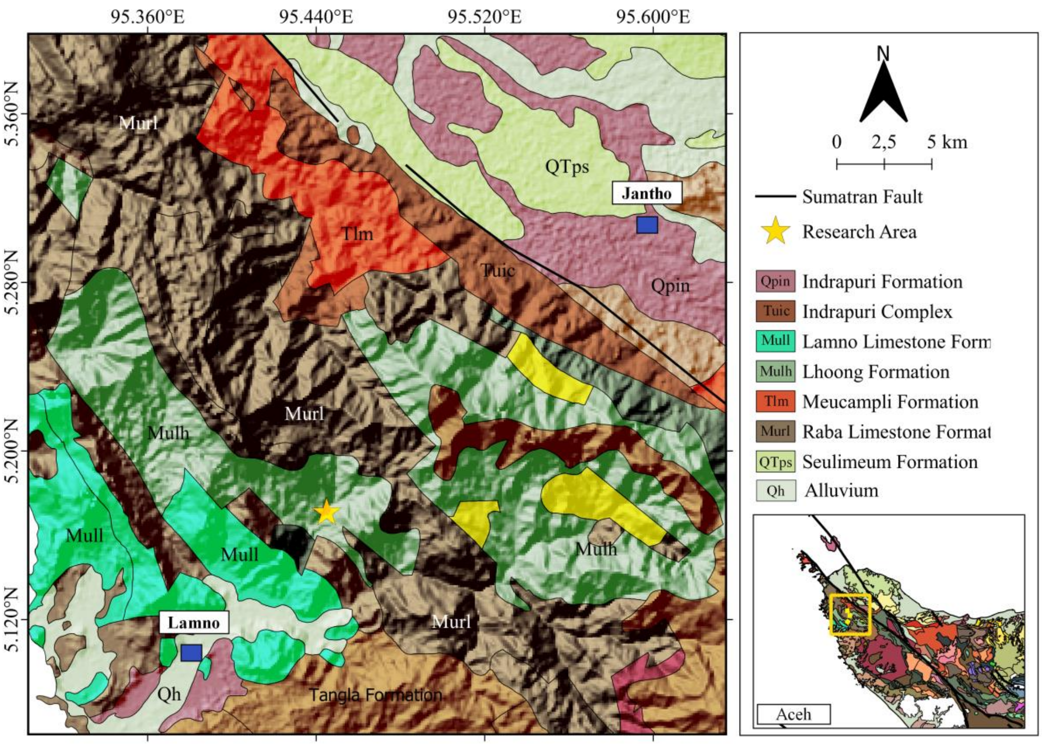


Fig.1 Geological Map of the Research Area, Modified from [15]

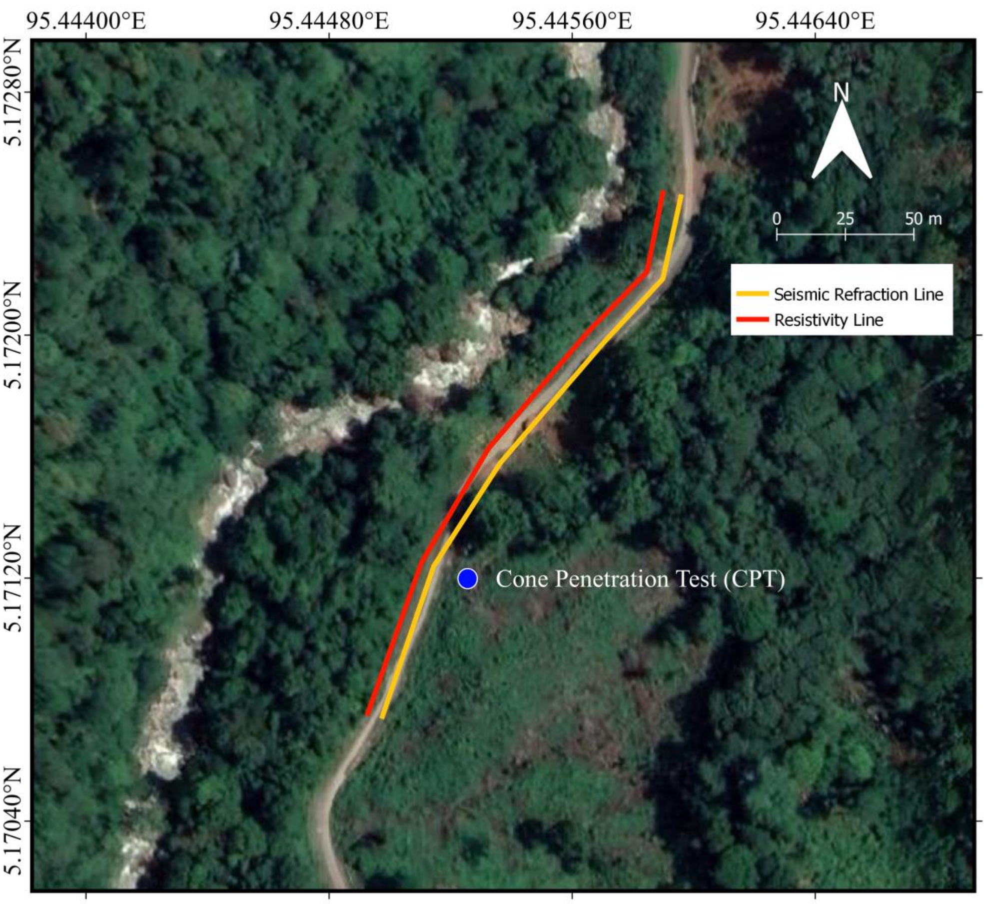


Fig. 2 The study area of geophysical and geotechnical survey

The Wenner configuration is a widely used elecrode layout in geolectric exploration, characterized by an arrangment with even spacing (r1=r4=a and r2=r3=2a). This configuration is utilized to determine the resistivity of rock layers below the surface by injecting electric current into the soil through two electrode points on the ground surface and two other points to measure the potential difference on the same surface [19]. The Wenner-Schlumberger configuration is a combination of the Wenner and Schlumberger configurations, with a constant system of spacing rules. The current electrode and potential electrode are greater than the distance between the potential electrode, and the potentials are a than the distance between the current electrode [20,21]. The currnet electrode distance is three times that of the potential electrodes, and the distance from the potential electrodes to the sounding point is 2/a. Consequently, the sounding point distance is 2/3a. This electrode arrangement provides exceptional vertical resolution and exhibits high sensitivity to lateral variation [22].

The seismic refraction method is a geophysical approach that capitalizes on the transmission of waves beneath the Earth's surface. Seismic waves are induced by a vibrating source, commonly a hammer, and captured by geophones functioning as receivers. The subsurface velocity of seismic waves showcases a range of values, constructing a model of subsurface structures in terms of depth. The recorded travel times of seismic waves are subsequently employed to interpret subsurface data, determining the wave velocity (Vp) as it traverses through the layers [23]. At its core, seismic refraction hinges on the variability (contrast) in the velocity of wave propagation when traversing distinct subsurface materials. The alteration in the direction of wave propagation towards a new medium yields valuable insights into the composition and structure of subsurface layers. This method proves particularly effective in recognizing and characterizing subsurface structures, rendering it an invaluable tool in geological and geotechnical inquiries [24].

The study mentioned falls within the realms of observational and in-situ research, as it involves gathering primary data through an investigation of the soil in Krueng Sabet, Lamno, using the Cone Penetration Test (CPT). The objective of the study is to capture the conditions of subsurface soil layers, including values for cone resistance (qc), total friction (Tf), local shear resistance to cone resistance (Rf = fs / qc), the presence of groundwater, soil porosity, and direct qualitative assessments of soil types based on the implementation of CPT/Sondir Test. The Cone Penetration Test (CPT) is a widely used in-situ test that provides valuable information about the subsurface stratigraphy associated with soft materials, discontinuous lenses, organic materials, and potentially liquefied materials (such as sand, silt, and granule gravel). It is also used to predict landslides or ground settlement. The data compiled from this testing is valuable for assessing the subsurface conditions and can be used to interpret the data on the site, enabling geotechnical engineers to gain a competitive advantage [25].

## 4. RESULT AND DISCUSSION

Field measurements were carried out within the coordinates of N 05.170760 and E 095.444940 to N 05.172490 and E 095.445930, aligning with the roadside. The data collection for this research comprised a singular line extending 240 m from the southwest to the northeast, reaching depths of 60 m. The weather conditions during the measurement activities ranged from overcast to drizzly.

After processing the data using Zondst2D software, the 240-m line exhibited P-wave velocity values ranging from 0.3 to 2.9 km/s as illustrated in Fig. 3. The subsequent depiction illustrates the 2D seismic cross-section along that specific line. The upper layer is denoted as Topsoil, consisting of a mixture of sand and clay. This is characterized by P-wave velocity values ranging from 0.3 to 1.9 km/s. This layer extends to an approximate depth of ±35 m from the surface and is saturated with water, making it weak. The second layer reveals Bedrock, identified as fresh Limestone, with velocity values ranging from 1.9 to 2.9 km/s, situated at a depth of approximately 20 m below the surface. The image serves as a model for the weak zone and its potential as a sliding plane at the measurement site. This sliding plane is saturated due to water saturation, influenced by the topography and steep slope.

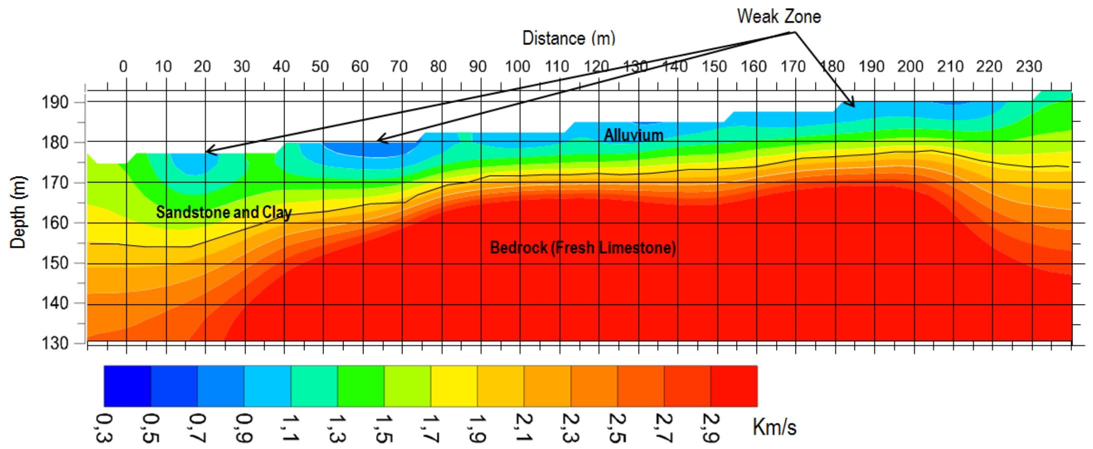


Fig 3. Predicted refraction seismic model

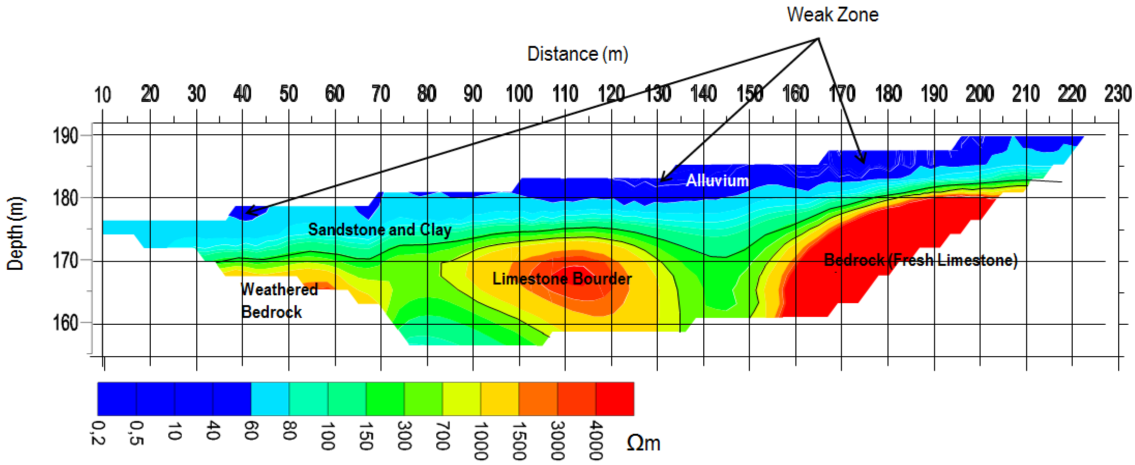


Fig. 4 Predicted electrical resistivity model

Geoelectric measurements using the Wenner–Schlumberger configuration were conducted along the same line as the seismic survey, with a length of 230 m, as illustrated in Fig. 4. The measurements yielded a depth of 30 m below the surface. Based on processing results using Res2Dinv software, resistivity values ranging from 0.2 to 4000 Ωm were obtained on that line. The qualitative interpretation of the indicates sediment deposits, a mixture of sand and clay, saturated with water. Correlating with regional geological data and geological observations in the surrounding area, the subsurface cross-section consists of three surface rock layers: Sand and Clay, Weathered Bedrock, Limestone Boulder, and Limestone. In the upper layer, spanning 35 to 220 m, resistivity values of 0.2 to 100 Ωm and depths of 0 to 7 m indicate sediment, a mixture of sand and clay. This layer is saturated with water, resulting in low resistivity values. The second layer, ranging from 35 to 210 m, exhibits resistivity values of 100 to 700 Ωm, indicating weathered Bedrock formed by the weathering of the bedrock beneath it, beginning to be saturated with water. The third layer, spanning from 85 to 135 m, shows resistivity values > 700 Ωm with a depth of approximately 15 m, indicating limestone boulders. These large rock formations are located below the surface, composed of hard limestone. Finally, from a distance of 150 to 205 m, with resistivity values > 700 Ωm and a depth of 10 m, there is an indication of hard limestone rock. The depicted image serves as a model created to illustrate the potential sliding plane in the measurement line. This sliding plane is a saturated zone due to water saturation from the surface, influenced by the slope's inclination, indicating the potential for landslides, as highlighted by low resistivity anomalies.

The determination of the slip plane in the Lamno area was accomplished by analyzing seismic and resistivity data, which revealed consistent dimensions (40-90 Ωm) within layers composed of sandstone and clay. Slope instability in this region was influenced by a gently undulating topography, with slopes ranging from ±40 degrees, characterized by a rotational slip type. Various methods for protecting the slopes were recommended for this sedimentary rock site, including shotcrete, wire mesh, net rock bolting, retaining walls, and targeted rock removal [26]. Additionally, proposed strategies included implementing a drainage system with the appropriate gradient, applying an asphalt layer, and utilizing biotechnical slope protection techniques [27,28]. These measures aimed to minimize potential slope hazards and improve overall stability.

CPT data provides valuable insights into the mechanical properties of the soil at various depths as illustrated in Table 1., Fig. 5 and Fig 6, assisting in identifying the potential presence of a Weak Zone or a weak zone within the soil structure. Data from CPT play a pivotal role in comprehending the likelihood of landslides in a specific area. In this context, linking CPT information with potential landslide occurrences becomes crucial. Firstly, the unclassified soil layer at the surface depth (0.00m) serves as a focal point. Unclassified soil may indicate instability or a lack of cohesion, signaling the susceptibility of the surface layer to ground movement. Subsequently, from a depth of 0.20m to 1.20 m, where the soil is predominantly clayey, there is potential for high moisture content and reduced stability. Clays have a tendency to absorb water effectively, leading to increased weight and moisture, pivotal factors that can trigger landslides, especially in the presence of other factors such as heavy rainfall. The transition to Silty Sands at a depth of 1.40m to 1.60m indicates a change in soil properties. While silty sands are generally more stable than clay, it's essential to note that they can still be vulnerable to erosion or reduced stability depending on specific conditions. The Fine Sands layer at a depth of 1.80 m to 2.00m has the potential to provide better stability. However, it's crucial to consider that even seemingly stable materials can be affected by external factors such as groundwater or additional loads.

CPT data is instrumental in unveiling the soil characteristics at various depths in the Krueng Sabet Lamno region. At the surface depth (0.00m), the soil's classification remains unclear. Nevertheless, as depth increases, variations in soil types become evident, including clays, clayey silts, silty sands, and fine sands. Particularly at a depth of 1.40m to 1.60m, the Cone Resistance (Qc) and Sleeve Friction (Fs) values exhibit a significant increase, signifying the presence of "Silty Sand," which can be considered a potential weak zone.

Tabel 1. Result CPT

| (m) | Cone Resistance Qc (Kg/cm$^2$) | Sleeve friction Fs (Kg/cm$^2$) | Est. Soil Type |
|---|---|---|---|
| 0,00 | 0 | 0,00 | Not Clasified |
| 0,20 | 50 | 3.01 | Clay |
| 0,40 | 50 | 3.01 | Clay |
| 0,60 | 65 | 3.68 | Clayey Silt |
| 0,80 | 65 | 3.68 | Clayey Silt |
| 1,00 | 55 | 3.01 | Clay |
| 1,20 | 55 | 3.01 | Clay |
| 1,40 | 135 | 8.02 | Silty Sand |
| 1,60 | 135 | 8.02 | Silty Sand |
| 1,80 | 150 | 9.03 | Fine Sand |
| 2,00 | 150 | 9.03 | Fine Sand |

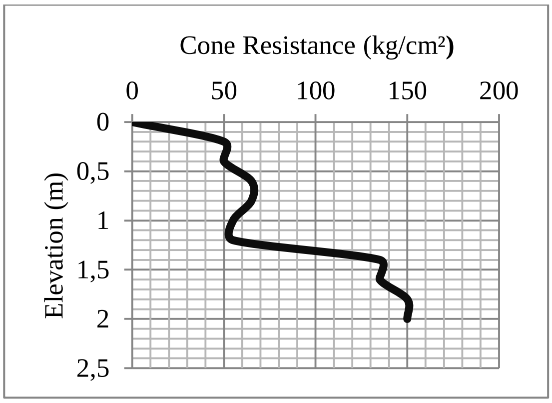

Fig. 5 Predicted Cone Resistance model from CPT data

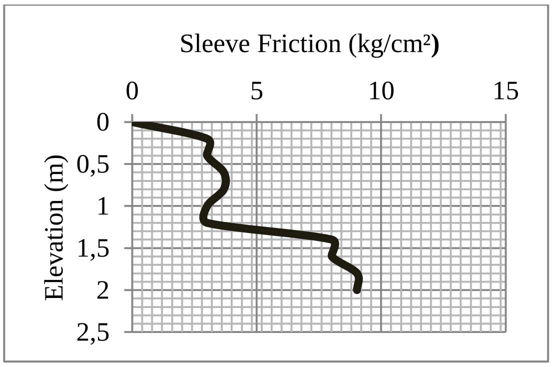

Fig. 6 Predicted Sleeve friction model from CPT data

CPT results in Table 1. further strengthen this interpretation by quantifying soil resistance and friction at various depths. In the shallow layers

(0.20–1.20 m), the soil is dominated by clay and clayey silt, with cone resistance (Qc) ranging from 50–65 kg/cm² and sleeve friction (Fs) around 3.01–3.68 kg/cm², indicating relatively weak and compressible material. At 1.40–1.60 m depth, a Silty Sand horizon emerges with significantly higher resistance (Qc = 135 kg/cm²) and friction (Fs = 8.02 kg/cm²). Although stronger in terms of penetration resistance compared to the upper clay layers, this silty sand is identified as the weak zone due to its susceptibility to saturation and reduced shear strength, making it a potential sliding plane. Deeper horizons (1.80–2.00 m) consist of fine sand, with Qc = 150 kg/cm² and Fs = 9.03 kg/cm², which indicates more stable and competent material.

Overall, CPT data not only identifies soil types at specific depths but also provides indications about potential weak zones in the area. Integrating this information with other factors such as topography, rainfall, and geological history can offer a deeper understanding of potential landslide risks in Krueng Sabet Lamno. Analyzing weak zones and soil characteristics forms a crucial foundation for effective disaster mitigation and risk management in the region

Fig.7 Limestone outcrop observed along the Lamno–Jantho road, approximately 5 m from the survey line. This outcrop indicates the regional presence of limestone lithology in the study area but does not directly correspond to the deeper limestone layer inferred from the resistivity model (Fig. 4). The formations also include detached rock fragments resulting from cliff landslides beside the road. In addition, an igneous rock identified in this area is andesite. Andesite typically forms from magma ejected during stratovolcanic eruptions, producing thick lava flows that may extend for several kilometers. The andesite observed at the site exhibits a whitish-gray color, closed porosity, compact packing, and no reaction to HCl. Its aphanitic texture indicates that individual crystals cannot be distinguished with the naked eye and therefore require microscopic examination.

Additionally, the andesite rock displays a massive structure, signifying the absence of flow properties and any incorporated fragments within its composition. Landslides and ground movements in Aceh Province result from several key factors, including active tectonic shifts, heavy rainfall, geological structures, weathering, and seismic activity. Mitigating these risks entails the

Fig 7. Limestone outcrops in the study area.

application of diverse slope stability and protection methods, chosen based on the specific composition and condition of the slope material [29]. Given the distinct stability characteristics of soil and rock slopes, tailored approaches are necessary for each. It is crucial to direct further research efforts towards evaluating rock mass, slope mass, and conducting kinematic analysis to gain a deeper understanding of landslide risks in Aceh Province. These studies are imperative for the development of effective strategies aimed at reducing the susceptibility to landslides in the region.

## 5. CONCLUSION

This study demonstrates that the integration of geophysical methods (resistivity and seismic refraction) with geotechnical analysis (CPT) provides a robust framework for assessing the potential of landslide disasters in Krueng Sabet, Aceh Jaya. The results identified the Silty Sand layer at a depth of 1.40–1.60 m as a critical weak zone that may serve as a potential sliding plane under rainfall or loading stresses. These findings offer practical guidance for local mitigation along the Jantho–Lamno corridor, where slope protection measures—such as drainage improvement, slope regrading, and retaining structures—should be prioritized. Furthermore, disaster management agencies are encouraged to integrate these results into early warning systems and community preparedness programs. Beyond the local context, this integrated geophysical–geotechnical approach serves as a transferable and scalable model for landslide hazard mapping, infrastructure planning, and disaster risk reduction in other vulnerable regions of Indonesia. To enhance resilience, long-term monitoring and the incorporation of identified weak horizons into engineering design standards are strongly recommended, ensuring that both localized interventions and broader policy frameworks effectively reduce landslide risks.

## 6. ACKNOWLEDGMENTS

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