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Volume: 14 | Number: 02 | October 2025 | ISSN: 1907-4247 (Print) | ISSN: 2477-4863 (Online) | Journal Homepage: https://cantilever.id

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Research Article

Preliminary Assessment of Building Damage Potential Due to Landslide (Case Study Gua Maria Kerep Ambarawa, Central Java)

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Received: 9 September 2025, Accepted: 16 October 2025, Published: 4 December 2025

Abstract

Landslides are complex phenomena that are frequently interpreted differently across disciplines due to their mechanisms and impacts on both nature and society. This paper presents an assessment of landslide vulnerability in the Gua Maria Kerep Ambarawa (GMKA) area, a Catholic pilgrimage site in Central Java, Indonesia. The study highlights the need to identify and classify disaster-prone areas to facilitate effective regulation, site development, and disaster mitigation efforts. Focusing on GMKA, the research employs a phased vulnerability assessment approach to map potential sources of landslide hazards, particularly following a surface landslide during the early 2024 rainy season. The observations indicate that water seepage and soil saturation around the graveyard area were key contributing factors. The movement of soil under the surface was detected using georadar, which measures the shear wave velocity of the soil layer under the surface. Visual indicators, such as gaps in masonry, can serve as an effective hazard prevention measure prior to conducting instrumental inspections.

Keywords: *Landslide, Shear wave velocity, Hazard prevention*

1. INTRODUCTION

Landslides are often interpreted differently by individuals in various fields of study due to their unique mechanisms and impacts on both nature and society. This difference and unique definition are a reflection of landslides as part of a complex problem that, most of the time, has a highly significant impact and affects nature itself (Highland & Bobrowsky, 2008). When landslides occur, they are often indicated by a sudden release of a huge amount of energy, which can be deadly. This phenomenon is caused by the intensity of land use change in mountainous areas for various human activities, which has the potential to trigger landslides. (Aletotti & Choudhury, 1999; Ghosh & Bhattacharya, 2010). Therefore, it is necessary to identify and classify disaster-prone areas that are prone to landslides. Identification and classification are expected to provide an overview of areas vulnerable to landslides, estimating the extent and intensity of potential landslide vulnerability. Thus, there will be several data points that are easily accessible to various parties who need them for the preparation of regulations, site development, and disaster mitigation. This identification and classification can only be done through a stage called assessment. The assessment of landslide occurrence is one of the interesting research topics in geotechnical engineering and structural engineering. Indeed, the impact of landslide vulnerability is enormous, starting from a single area and extending even to a regional level.

Additionally, it is not impossible for a landslide to also serve as a trigger that influences economic and social activities. (Ciampalini et al. 2014; Cotecchia et al. 2014, 2015, 2016; Petley 2012). As for vulnerability, according to the United Nations (UNDRO, 1979), it relates to the potential for an event to occur, which can be determined through qualitative, semi-quantitative, or quantitative methods. The potential is expressed in terms of loss, loss of gain, damage, injury, or loss of life. The purpose of this study is to assess the potential for

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DOI: https://doi.org/10.35139/cantilever.v14i2.556

landslides. Based on the explanation above, the purpose of this study is to assess the potential for occurrence in the Gua Maria Kerep Ambarawa (GMKA). Gua Maria Kerep Ambarawa is a Catholic pilgrimage site located in Ambarawa, Semarang Regency, Central Java, Indonesia. Gua Maria Kerep Ambarawa (GMKA) is a precursor to the emergence of Marian caves in Indonesia after Gua Maria Sendangsono in Kulonprogo Regency (DIY) and Gua Maria Sriningsih in Klaten Regency, Central Java. Geographically, GMKA is located at the coordinates of Gua Maria Kerep Ambarawa: 7°15’19″S 110°23’58″E. Based on the preliminary assessment, a surface landslide occurred during the rainy season in early 2024. It was suspected that water coming down the stairs and water seepage from the graveyard down the ravine saturated the soil grains with water. Seepage around the graveyard area created a cavity under the existing concrete pathway, which sits on top of the slope. As an illustration of the initial assessment, the existing conditions can be shown in Figure 1. Initial research results mapped potential sources of vulnerability in the GMKA area. Furthermore, in conducting the initial assessment of vulnerability at GMKA, the phased approach developed by Palmisano (2011) was used.

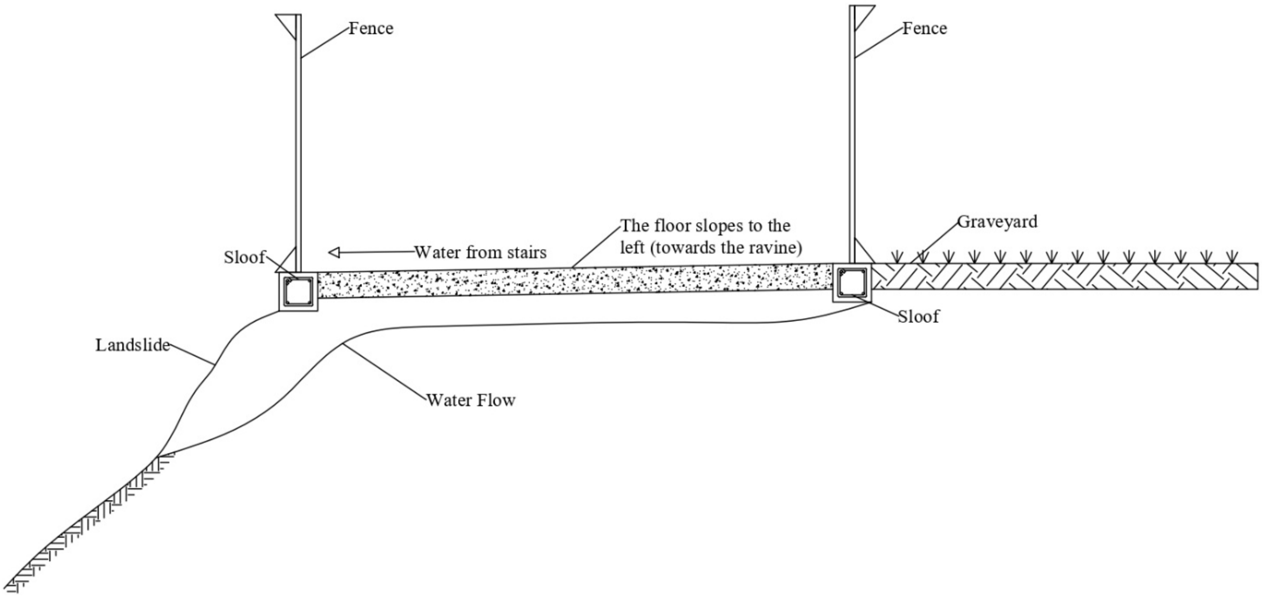

Figure 1. Cross-section of the landslide area near the graveyard

Landslide: The impact and significance

According to UNISDR (2017), the term landslide refers to a variety of processes that result in the downward and outward movement of slope-forming materials, including rock, soil, artificial fill, or a combination of these. The material may move by falling, rolling, sliding, spreading, or flowing. A schematic illustration of landslides is shown in Figure 2.

Almost everywhere in the world, landslides are a frequent natural threat that poses a risks to people and the environment. Threats to humans and the environment can include socio-economic factors, and secondly, they can trigger a mass migration. Migration that occurs has the potential to occupy sloping areas. (Aleotti & Chowdhury, 1999; UNISDR, 2017). For example, a case study in Australia, according to the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) (EM-DAT), since 1900, some 130,000 persons have lost their lives because of landslides and flash floods, and the-

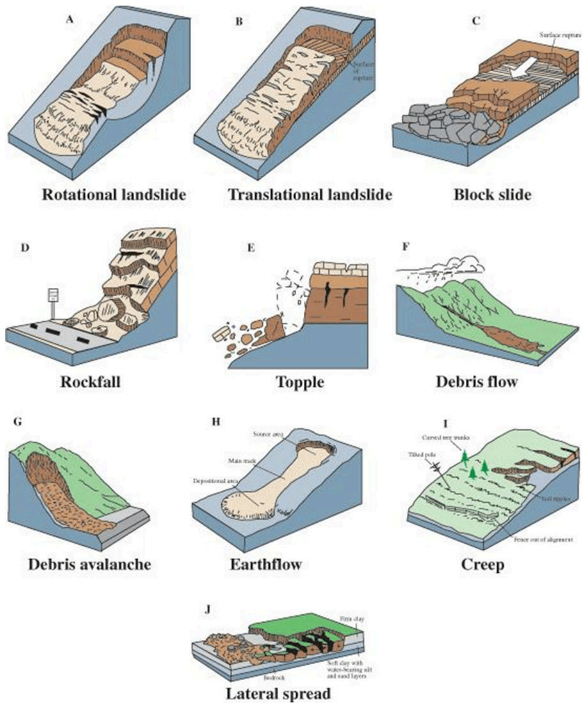

Figure 2. Landslide illustration (Source: UNISDR, 2017)

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economic losses amounted to over US$50 billion. Between 2000 and 2014, the corresponding figures were approximately 26,000 deaths and US$40 billion in losses. The actual figures, however, are much higher (UNISDR, 2017).

In the CRED-EM database, losses due to earthquake-triggered landslides are attributed to earthquakes. However, many landslide events with no casualties but significant material losses are not reported. For example, 20-25 percent of the 87,000 casualties (69,000 confirmed killed and 18,000 missing) caused by the Sichuan (or Wenchuan) Earthquake of 12 May 2008 were the result of the landslides triggered by that event. Recent catastrophic landslides in Afghanistan, the United States, the Philippines, and India illustrate that landslides remain a major threat in both developed and developing countries (UNISDR, 2017). While in Indonesia, landslides are the fourth leading source of disaster, as exemplified by a case study in Indonesia, following floods, forest and land fires, and extreme weather. The frequency of landslide events from 1 January to 1 September 2024 was 88 events, as shown in Figure 3.

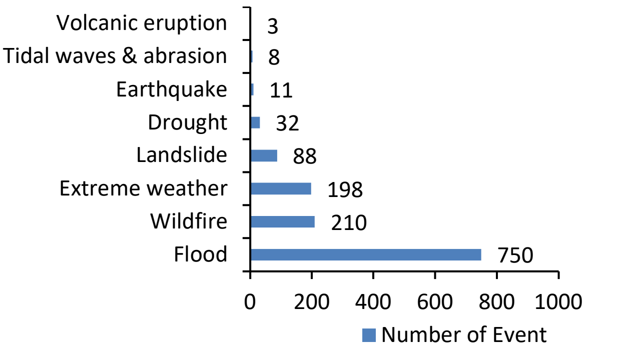


Figure 3. Number of natural disasters in Indonesia during the period 1 January – 1 September 2024 (Source:https://databoks.katadata.co.id/demografi/statistik/66d7d7a492e96/ada-1300-bencana-alam-di-ri-sampai-september-2024-ini-rinciannya)

On a larger scale, landslides can have a significant impact on economic activity, including the Gross National Product. Many cases in some countries contribute to stagnant economic conditions and even affect economic growth (Hutchinson, 1995; Mora, 1995). Although the impact of landslides is significant, their importance is often overlooked because the damage caused by landslides is often considered a result of the triggering process of other natural disaster phenomena, such as earthquakes, floods, and others (Schuster 1996, as cited in Aleotti & Chowdhury 1999).

Things that Trigger Landslides

According to UNISDR (2017), the main factor that leads to the incidence of landslides are:

1) River erosion, glaciers, or ocean waves
2) Weakening of rock and soil slope properties through water saturation by snowmelt or heavy rains stresses, strains, and excess of pore pressures induced by the inertial forces during an earthquake (earthquakes of magnitude greater than or equal to 4.0 can trigger landslides)
3) Volcanic eruptions with the production of loose ash deposits that may become debris flows (known as lahars) during heavy rains
4) Stockpiling of rock or ore, from waste piles, or from man-made structures
5) Changes in the natural topography caused by human activity

2. METHODS

In this study, the assessment was conducted using the detailed building investigation approach developed by Palmisano (2016). The complexity of the investigation and the large diversity of elements that are indicated to be vulnerable require the investigation to be grouped in a hierarchy, as shown in Figure 4. The purpose of this hierarchy is to determine the level of vulnerability so that mitigation treatments in the short, medium, and long term can be determined.

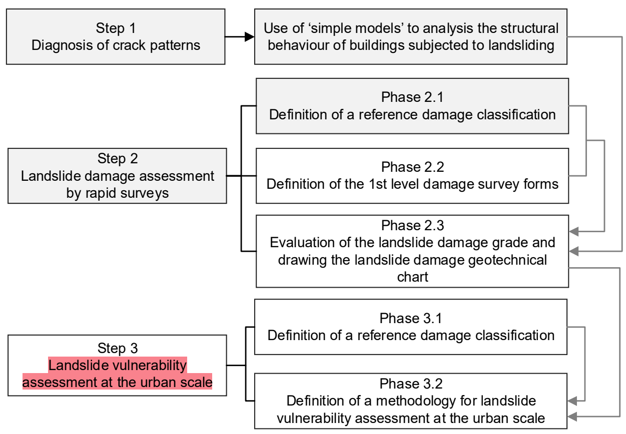


Figure 4. Staging of the landslide assessment (Source: Palmisano, 2011)

Based on Figure 4, it can be shown that at the first level, the assessment is carried out by diagnosing the characterization of the crack pattern in the building. Assessment can be done by surveying the field through observation. The information obtained can be used to recognize the landslide morphology. The results of georadar testing are discussed in the analysis section. Furthermore, the second level in Figure 4 is illustrated, which is the main object of this article, aiming to provide fast and objective data using georadar. The focus of this study is on Level 1 and Level 2 in the section defining landslide damage. The third level utilizes the results of the previous steps and aims to assess structural landslide susceptibility. In particular, the geometry, structural, and historical data about the building, obtained in Step 2, are used as input data for structural vulnerability evaluation. Damage data are also useful in this step to further support the characterization of landslide-structure interaction. The third level part will be focus of research in the next stage.

3. RESULT & ANALYSIS

Based on the phasing depicted in Figure 4, the diagnosis was conducted through a field survey to determine the behavior of the structure identified as having landslide potential. The survey implementation can be shown in Figure 5.

a. The existing wall that is indicated to have the potential to collapse due to landslides

b. Road access warning around the GMKA area

c. Early mitigation to prevent more severe landslides

Figure 5. Field survey to obtain the behavior of the structure indicated as having landslide potential

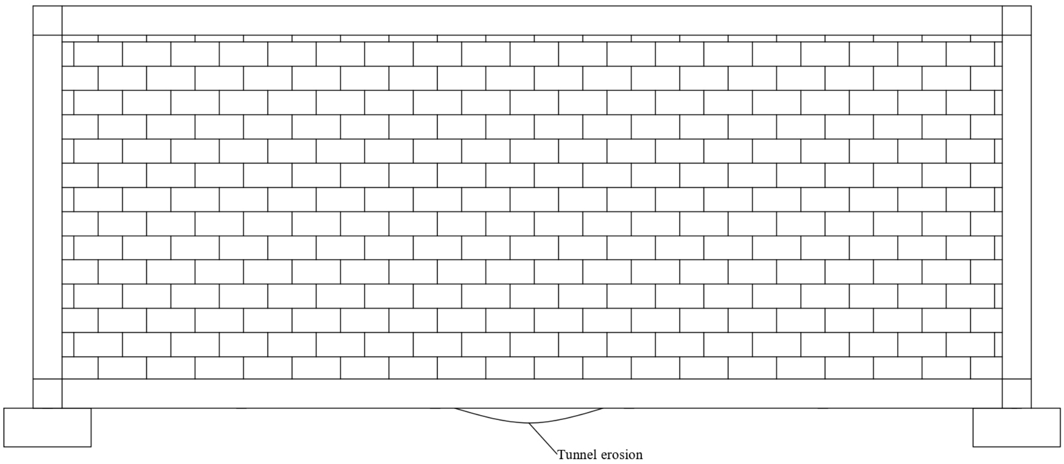


Figure 6. Illustration of wall damage due to slump vulnerability

Based on the survey, the causes of potential landslides on the walls surrounding the GMKA area were identified through an illustration, as shown in Figure 6.

Visual identification results obtained the cause of the hole in the wall, as follows:

1) Surface water enters under the sloof, causing erosion, or
2) Behind the wall, there is soil surface erosion.

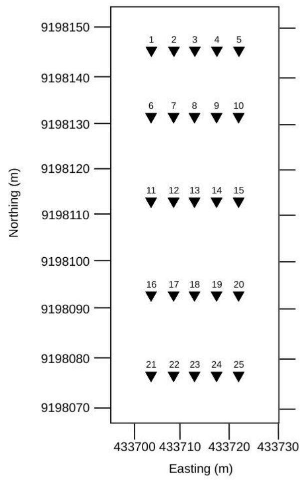
Both of these factors reduce the soil's bearing capacity for the foundation, leaving only the upper beam strong and causing it to bend in the middle of the span between columns. Behind the concrete block wall, there is a ravine and some landfill, which keeps some parts of the wall straight due to the support from the landfill. Next, geotechnical testing was conducted to determine soil deformation in the area shown in Figure 5c, using georadar. The research location is shown in Figure 7. The coordinates of the Georadar testing location can be shown in Table 1.

DOI: https://doi.org/10.35139/cantilever.v14i2.556

Figure 7. Georadar testing layout

Table 1. The coordinates of the georadar testing Location

Point	X	Y	Z	Point	X	Y	Z
1	433704	9198144	0	14	433716	9198112	-3
2	433708	9198144	0	15	433720	9198112	-3
3	433712	9198144	0	16	433704	9198094	-3.5
4	433716	9198144	0	17	433708	9198094	-3.5
5	433720	9198144	0	18	433712	9198094	-3.5
6	433704	9198130	-3	19	433716	9198094	-3.5
7	433708	9198130	-3	20	433720	9198094	-3.5
8	433712	9198130	-3	21	433704	9198076	-3.5
9	433716	9198130	-3	22	433708	9198076	-3.5
10	433720	9198130	-3	23	433712	9198076	-3.5
11	433704	9198112	-3	24	433716	9198076	-3.5
12	433708	9198112	-3	25	433720	9198076	-3.5
13	433712	9198112	-3				



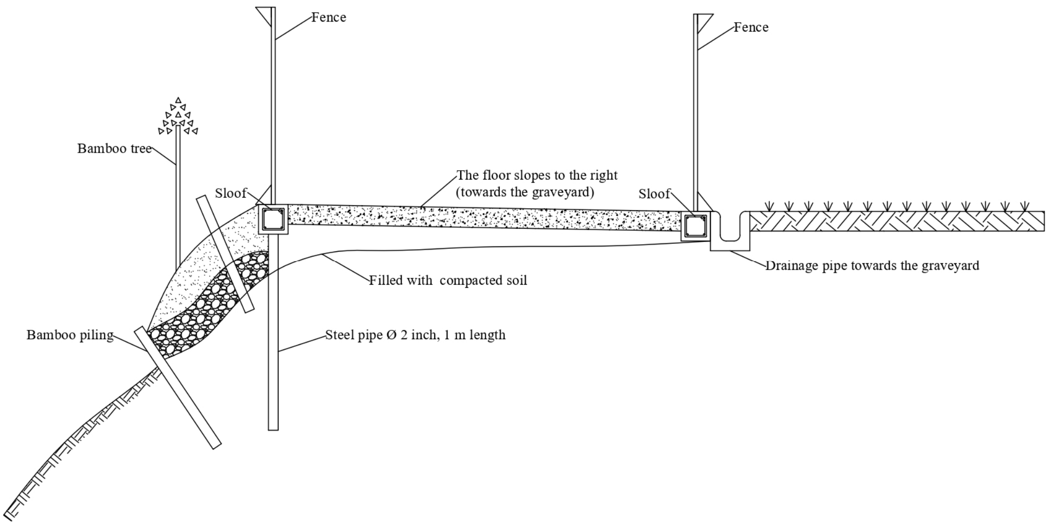


Figure 8. Shear Wave Velocity of The Soil Layer at GMKA

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At the initial stage of the implementation of this research, there are two parameters used to analysis, namely:

1) Shear wave velocity (Vs)

Soil is a granular material that allows waves to propagate longitudinally and shear. Unlike Primary waves that rely on coupling so that they can propagate through solid and liquid media, shear waves are highly dependent on the strength of a material to withstand shear forces. The ultimate strength of the soil itself is often referred to as the soil shear strength, which is the amount of shear force the soil can withstand before failure. The correlation of these two properties makes in this condition to be able to check the strength of the soil and its condition whether the shear force has been mobilized, a test is selected that determines the speed of shear waves moving in the soil with the mapping results shown in Figure 8 the mapping focuses on the magnitude of the shear wave velocity and is categorized at the limits of important soil shear strength values. According to SNI 1726-2019, the shear wave velocity at a depth of -30 meters below the ground surface is between 350 and 700 m/s, indicating that it falls within the Hard or SC soil classification. Where exactly between -40 m, the bedrock transition limit specified by SNI is found, at 750-1500 m/s, or the SB limit. This result indicates a bedrock layer that is relatively close to the surface soil.

Table 2. Classification of rock sites based on wave speed S based on SNI 1726-2019

Site Class	Vs (m/s)
SA (Hard Rock)	≥ 1500
SB (Rock)	750 - 1500
SC (Very Dense Soil and Soft Rock)	350 - 700
SD (Stiff Soil)	175 - 350
SE (Soft Soil)	≤ 175 or any soil profile containing more than 3 m with the following characteristics: 1. Plasticity Index Plasticity, PI > 20, PI > 20 2. Water Content, w ≥ 40% 3. Undrained Shear Strength, $S_u < 25\ kPa$

Table 3. Classification of soil types according to Keceli (2012)

Soil and Rock Type	Vs (m/s)
Soft and Sturated	< 100
Loose and soft	100 - 400
Moderate Stiff but altered	400 - 700
Stiff	700 - 1500
Very Stiff	1500 - 2700
Hard and massive rock	2700 - 4000

Based on the results of research with georadar obtained data that the clay layer which in the analysis of ground motion serves as a sliding field is located under Point 21 to Point 23 with a depth of about 8 m The depth of bedrock (Vs = 1000 m / s) is identified at a depth of 20 m at higher elevations, to a depth of 50 m at the lowest elevation in this study.

2) Ratio Vp/Vs

The Vp/Vs ratio is the ratio of the compression wave (or P-wave) velocity to the shear wave (or S-wave) velocity. A Vp/Vs ratio above √3 is a soil layer condition with high porosity. The higher the Vp/Vs ratio, the greater the porosity of the rock, which causes water to accumulate in the rock. The Vp/Vs ratio value determines the lithology of the rock layer. Soil and rock types based on the Vp/Vs ratio are given in Table 4.

Eberhart-Phillips et al. (1989) showed that the ratio between P-wave and S-wave velocities (Vp/Vs) is more sensitive to changes in effective stress than P-wave velocity alone. Under low effective stress conditions, usually due to high pore pressure, the Vp/Vs ratio tends to increase, while under high effective stress conditions (with low pore pressure), it tends to decrease. This change is closely related to the elastic properties of the rock or soil. As the pore pressure increases, the soil becomes more easily deformed, causing the S-wave velocity to decrease more significantly than the P-wave velocity, resulting in an increase in the Vp/Vs ratio.

Table 4. Classification of soil and rock types according to Keceli (2012)

Soil and Rock Type	Vp	Vs	Vp/Vs	Safety Factor (SF)
Hard and massive rock	4200 - 6000	2700 - 4000	1,45 - 1,5	1,5
Very Stiff	4200 - 3000	1500 - 2700	1,5 - 2	1,5 - 2
Stiff	3000 - 2300	700 - 1500	2 - 3	2
Moderate Stiff but altered	1500 - 2000	400 - 700	3 - 4	3
Loose and soft	600 - 1500	100 - 400	4 - 6	3 - 4
Soft and Sturated	<1300	<100	5 - 8	4 - 5

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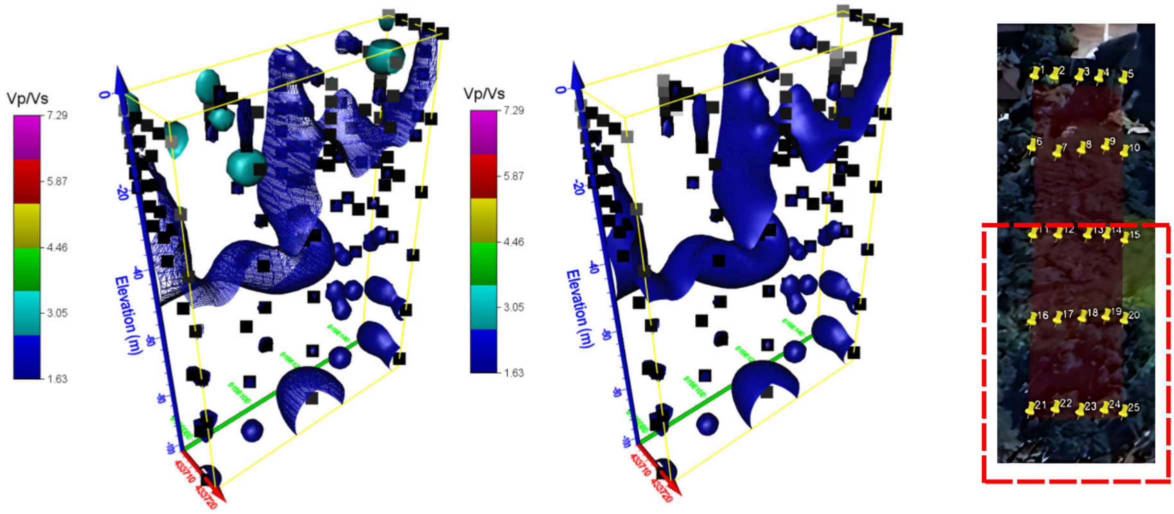

Figure 9. Ratio of P and S wave propagation speed in GMKA

Effective stress not only affects seismic wave characteristics, but is also a major factor determining soil strength. In soil mechanics, shear strength is influenced by the magnitude of the effective stress acting on soil grains, not by the total stress. Therefore, changes in the Vp/Vs ratio can serve as an indirect indicator of changes in soil strength, particularly in the context of slope stability analysis, active fault zones, or water-saturated soil conditions prone to liquefaction and seismic deformation. Based on the georadar results, soil layers with Vp/Vs = 2 were identified below Points 21-25 and Points 11-15. In some locations, soil layers that are indicated to be altered (Vp/Vs =3) were identified. Therefore, at this location, it is suspected that a mobilized shear force already exists, which contributes to the current landslide condition.

3) Rigidity

Rigidity, also known as the shear modulus, is a fundamental material property that quantifies a substance's resistance to shear stress without any volume change. It represents the material's response to shear deformation. Essentially, a material with high rigidity is very stiff and highly resistant to changes in its shape when subjected to a tangential force. Based on the GPR result, the lowest rigidity record is around 0.5–1 GPa, which was recorded at a depth of 20 m, specifically at area points 11 to 15 and 16 to 20 in the testing layout shown in Figure 10.

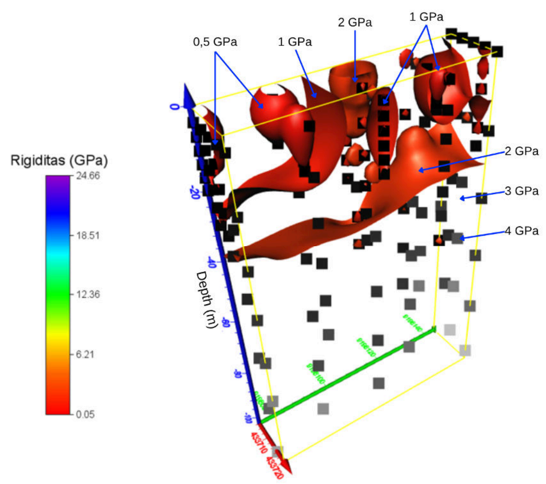

Figure 10. Rigidity of the soil layer in GMKA based on the GPR test

4) Ground Shear Strain

In general, Ground Shear Strain (GSS) refers to the ability of a material to deform or stretch under the influence of vibrational energy, such as that caused by an earthquake or other seismic sources. The magnitude of GSS directly impacts the potential for damage to soil layers during such events.

The relationship between Ground Shear Strain and the dynamic properties of soil is crucial for assessing site-specific seismic hazards. As a soil layer experiences ground motion, its internal structure is subjected to shear forces. A higher GSS value indicates that the soil is experiencing greater deformation, which in turn suggests a higher likelihood of significant damage, including phenomena like liquefaction, ground cracking, and subsidence. The dynamic behavior of the soil, which includes its shear modulus and damping, determines how it will respond to this strain. Typically detailed in Table 5, Nakamura (1997) demonstrated that GSS values are correlated with observed damage potential.

Table 5. Relationship between ground shear strain (GSS) and dynamic soil properties (Nakamura, 1997)

	10^{-6} 10^{-5}	10^{-4} 10^{-3}	10^{-2} 10^{-1}
Phenomena	Wave, Vibration	Crack, Settlement	Land Slide
Dynamic Properties	Elasticity	Elasto-Plasticity	Collapse
			Speed-Effect of loading

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Based on the GPR, a GSS is 1 x $10^{-3}$was recorded in the lane between points 16 and 20, and 21 and 25. According to Table 5, the relationship between the GSS values and soil conditions indicates the presence of ground cracks and surface subsidence in the area, as visualized in Figure 11.

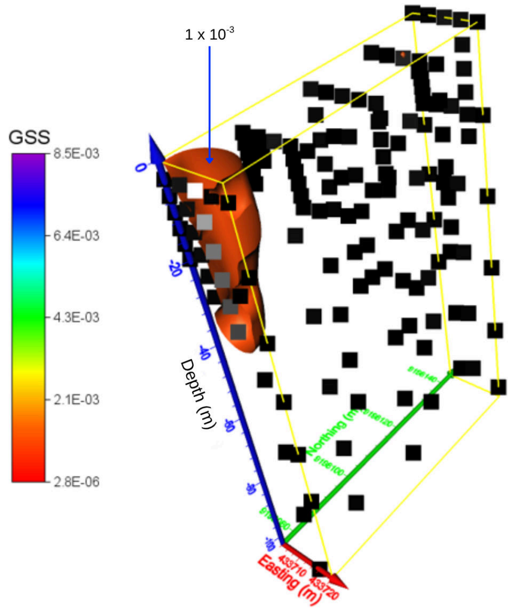

Figure 11. GSS value in the landslide area

Additionally, according to Table 5, cracking is also recorded in point 15, where the GSS value is 2 x 10^{-4}, as shown in Figure 12. These findings also align with the actual landslide that occurred,

4. CONCLUSION

Based on the results of the research, it can be concluded:

1) The deformed soil layer is located at the boundary between a low-hardness rock formation and a soil/rock infill in the lower southern area.
2) This boundary has a Vp/Vs ratio that is higher than typical values for rock layers, forming a connected layer that extends from a higher to a lower elevation. It also represents the lowest-rigidity layer at the study site, stretching towards the lower elevation.
3) The deformed soil layer has a Ground Shear Strain (GSS) value of 2 x 10^{-4}, which is associated with visible cracking and settlement. Its dynamic behavior is characterized by elasto-plasticity.
4) The depth of this anomalous soil layer extends to the bedrock, which is located approximately 50 meters below the surface.

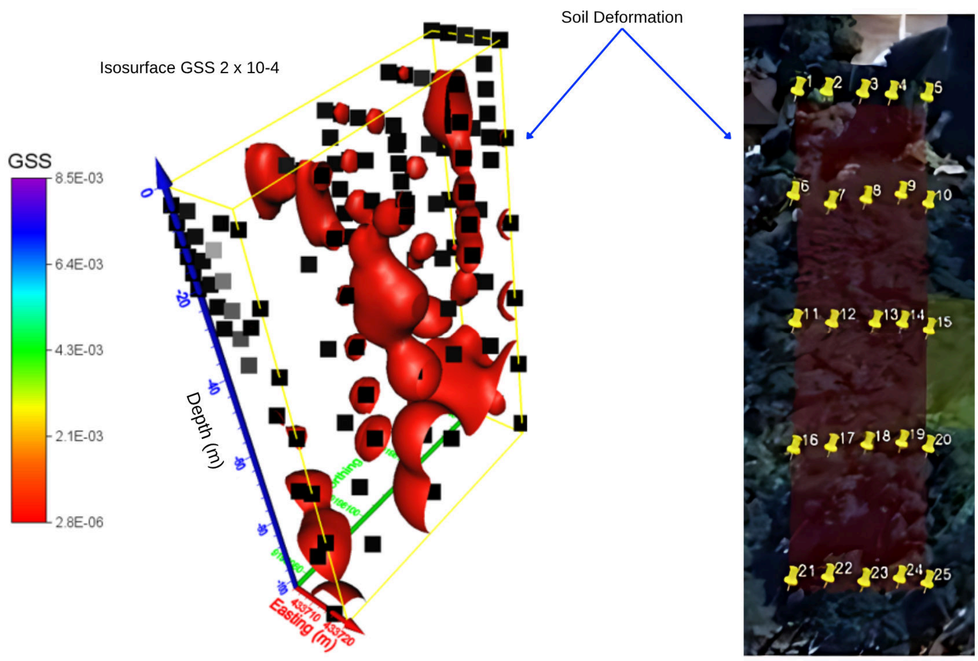

Figure 12. GSS value in the area where ground cracks present

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