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Classification and Friction Angle from CPT in Gneissic Residual Soil of Brazil

Fábio K. Silva[1], César S. Godoi Li[2] and Fernanda S. Schuch[1]

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Landslide Vulnerable Zones Based on Engineering Geological Assessment, Case Study: Wonotopo Area, Gebang District, Purworejo Regency, Central Java, Indonesia

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Abstract: Landslide is one of the geological disasters that frequently occur on the natural slopes, often threatening community of the adjacent area. Therefore, it is necessary to hold engineering geological research and assessment in disaster-prone regions such as Gebang district of Purworejo Regency, Central Java Province, Indonesia. This research was conducted to determine and analyze the type of mass movements, factor of safety, potential landslide areas, vulnerable zonation, factors influencing the stability of the slope, and to propose the disaster mitigation recommendation. The methods applied in the research are surface geological mapping, physical soil-rock properties testing, engineering geological assessment and analysis, and Regulation of Minister of Public Works of Republic of Indonesia number 22/PRT/M/2007, on Guidelines to Spatial Planning for Landslide Disaster Areas. To create information on the threats of land movements, a map on landslide potential zonation is developed by considering seven important aspects including: slope inclination, soil conditions, slope constituents, rainfall, slope water condition, seismicity, and vegetation or land use. The results show that, the landslide prone zone of the study area can be divided into 2 types, namely type B and type C. Landslide potential zone of type B involves high level of vulnerability and moderate level of vulnerability. Meanwhile, the landslide potential zone of type C consists of high level of vulnerability and low level of vulnerability.

Key words: Landslide, vulnerable zone, engineering geological assessment, mitigation, Wonotopo Area.

1. Introduction

Environmental problems that often occur in Indonesia are landslides as a result of ground movements. Ground movements in general are very detrimental to humans because they are destructive to various facilities and infrastructure, such as roads, bridges, irrigation channels, tunnels, housing, and land use. Today's rapid population growth has resulted in increasingly dense residential areas, including those located around steep slopes, such as Bagelen, Bener, Gebang, and Loano districts, Purworejo Regency, Central Java, where landslide disasters often occur.

This research was conducted by engineering geological investigation and analyses to determine and map the potential area of ground movements, factors influencing the movements, and to develop landslide disaster mitigation. The location of the case study area is Wonotopo and surroundings, Gebang District, Purworejo regency, Central Java as shown in Fig. 1.

2. Method of Study

Methods of this study include surface engineering geological mapping, remote sensing by using satellite imageries, secondary and primary data assessments, and analyses. Undisturbed samplings were done for soil-rock physical and mechanical properties testings. Slope stability analyses were carried out by utilizing Fellenius and Bishop methods [1], while the safety factors of some slopes were determined by applying

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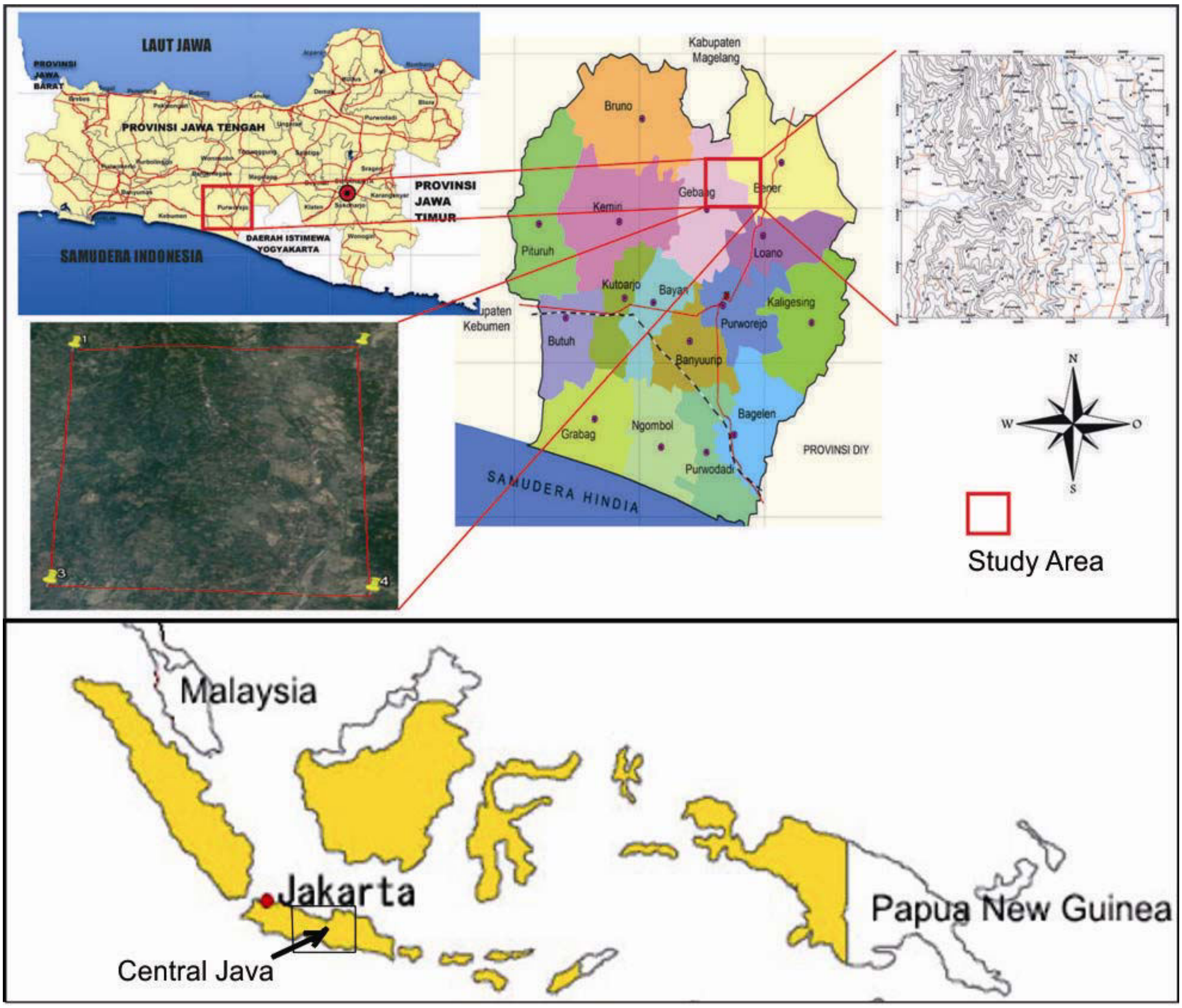

Fig. 1 Location map of the study area.

Slide 6.0 software.

2.1 Fellenius Method

According to the Fellenius method, in determining the safety factor of a slope, it has to be divided into several slices. Force distribution of the slope can be shown in Fig. 2. The force acting on a slice is parallel to the angle of the base of slice. Safety factor (FS) is calculated by the balance of stresses working on the slope. Fellenius states that slope failure occurs through the rotation of a ground block on a circular surface with "O" point as the center of rotation. This method also assumes that the normal force, *P* works in the middle of a slice. It is also assumed that the forces resultant on each slice are zero, or in other words, the forces resultant ARE ignored.

The data needed to determine FS values are as follows:

- Slope data, needed to make cross sections, including: slope angle, slope height, or slope length from the foot of the slope to the top of the slope.
- Soil mechanical data, consisting of internal friction angle (Φ), unit weight of wet soil (γ wet; g/cm³ or kN/m³ or ton/m³), cohesion (c; kg/cm² or kN/m² or ton/m²), and moisture content of soil (ω, %).

2.2 Bishop Method

The Bishop method is used to analyze the slip surface of circular shape [1]. In this method it is assumed that the total normal forces work at the center of the slice base, and can be determined by describing the forces on the slices vertically or normally. Balance requirements are used on the slices that make up the slope. The Bishop method assumes that the forces acting on the slice have a resultant equal to zero in the vertical direction.

2.3 Slide 6.0 Software

Calculation of slope stability analysis using the Slide program requires data namely slope coordinates and

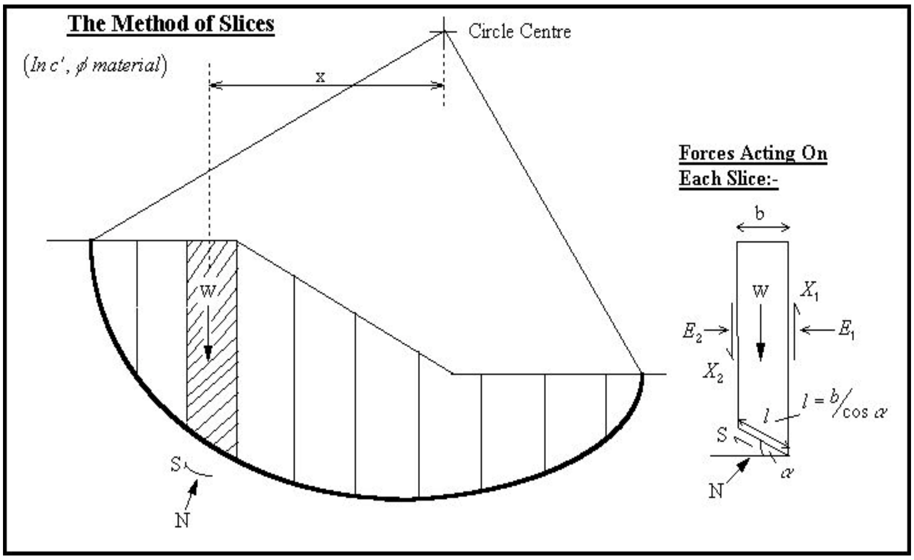

Fig. 2 Fellenius method of slices for determining safety factor.

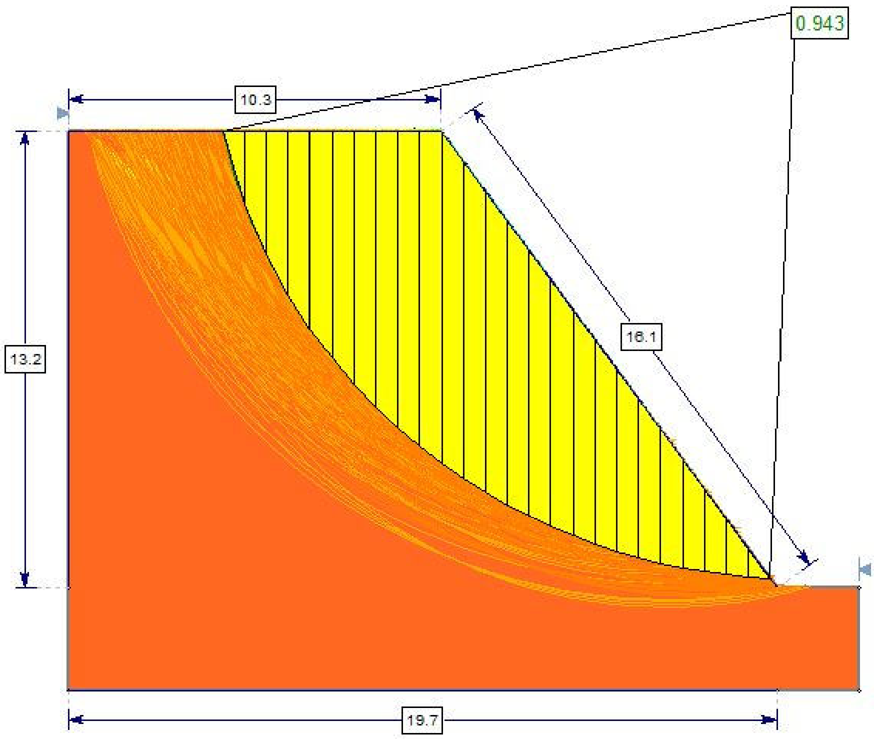

Fig. 3 Safety factor model determination using Slide 6.0 Software.

Table 1 Slope stability classification based on the value of safety factor [12].

FS Value	Class	Landslide occurrence intensity
FS < 1.07	Unstable	Frequently to occur
FS 1.07-1.25	Critical	Rarely to occur
FS > 1.25	Stable	Almost never to occur

slope land data (c, Φ, and γ). Slope data can be obtained from the results of rock/soil properties laboratory testing. This software is able to automatically compute the smallest safety factor value of a slope based on the input of required parameters of the slope (Fig. 3).

Based on the intensity of landslide occurrence and the value of safety factor, slope stability can be classified into 3 (three) classes [2], as shown in Table 1.

3. Engineering Geological Assessment and Analyses

3.1 Geology

Based on physiographical division map [3], the research area belongs to the Kulon Progo zone or Menoreh Hills. Regionally, lithostratigraphic setting from the older to the younger age consists of Nanggulan Formation, Kaligesing Formation, Dukuh Formation, Jonggrangan Formation, Sentolo Formation, Quaternary volcanic deposits and alluvial deposits.

The Nanggulan Formation consists of lignite insertion sandstones, claystone with limonite, marl, tuffaceous sandstone, Middle Eocene to Early Oligocene [4-6]. The Nanggulan Formation is overlain by Old Andesite Formation [6] or Kaligesing Formation and the Dukuh Formation [6]. The Kaligesing Formation is characterized by monomixed breccias, with andesite fragments, inserted by andesite sandstones and lava while the Dukuh Formation comprises polymixed breccias with andesite fragments, sandstones and limestones. The age of the formation is Late Oligocene-Early Miocene [4, 6, 7]. Above the Kaligesing-Dukuh Formation there are the Jonggrangan Formation and Sentolo Formation. The Jonggrangan Formation is characterized by tuffaceous marbles and sandstones with lignite insertion, the top of which is transformed into layered limestones and reef limestones. While the lower Sentolo Formation is characterized by interlayering of claystone and sandstone, towards the top it turns into marly sandstone and tuff insertion. The Sentolo Formation is unconformably overlain by Merapi volcanic deposits consisting of tuffs, lapilli tuffs, breccia, and andesite agglomerates [6, 7].

Referring to Van Zuidam [8], the geomorphology of the Wonotopo Region and its surroundings includes the undulating and hilly classification with slope inclination varying from steep, moderately steep, sloping, and gently sloping. The steep slopes are at an altitude of 100-300 meters above sea level, slope ranges from 30%-70% or 16^o-35^o. Areas with moderately steep slopes are at an altitude of 75-300 meters, slope ranges from 15%-30% or 8^o-16^o. Areas with sloping slopes are at an altitude of 140-200 meters, slope ranges from 7%-15% or 4^o-8^o. The area included in the gently sloping classification is at an altitude of about 50 meters, a slope of 2%-7% or 2^o-4^o. Developing river flow patterns are rectangular, dendritic, and sub-dendritic.

The stratigraphic sequence from the oldest to the youngest respectively comprises Kaligesing-Dukuh Volcanic Breccia Unit, Sentolo Limestone Unit, and Alluvial Deposits. Kaligesing-Dukuh Volcanic Breccia Unit consists of breccias with andesite matrix and fragments. At the top, there are fragments of limestone and shells of mollusks. The lower volcanic breccia is cemented by silicic, while the upper part by carbonate. Therefore it can be interpreted that the volcanic breccia depositional environment is gradually from terrestrial to marine environment. The stratigraphic relationship between the upper part of volcanic breccia and the lower part of layered limestone is interfingering [9]. Thus, the age of volcanic breccia is from the Late

Oligocene to the Early Miocene. Sentolo Limestone Unit consists of layered limestone. Based on the discovery of *Globorotalia obesa* fossils, *Globigerina riveroae*, *Globigerinoides immaturus*, *Globorotalia plesiotumida*, *Globigerina nepenthes*, it can be concluded that this unit has an early Miocene age range to the Pliocene (N12-N19). Based on the finding of fossils of *Eponides tenera*, *Eggerella scabra*, *Textularia pseudogramen*, *Textularia agglutinans*, and *Cibicides praecintus*, it shows that the bathymetry environment is in the outer neritic zone with a depth of 100-200 m. Alluvial deposits consist of loose material from weathering and erosion process of the older rocks, in the form of unorganized deposits, dominated by clay-sized and partially sand-sized textures.

The geological structures found in the study area are in the form of joints and fault with the Northwest-Southeast general pattern. The strike of the fault is also Northwest-Southeast, in the form of lateral slip faults (Fig. 4).

3.2 Slope Stability and Landslide Potential Zone

Slope stability analysis is needed for an area that is potential for mass movement, especially if the area is utilized for land use related to people’s lives. Mass movement is the transfer of rocks, soils, or debris downward through a slip plane under the influence of gravity [10]. The main influencing factors are steep slope inclination, high rainfall, groundwater content, and intensive weathering rates.

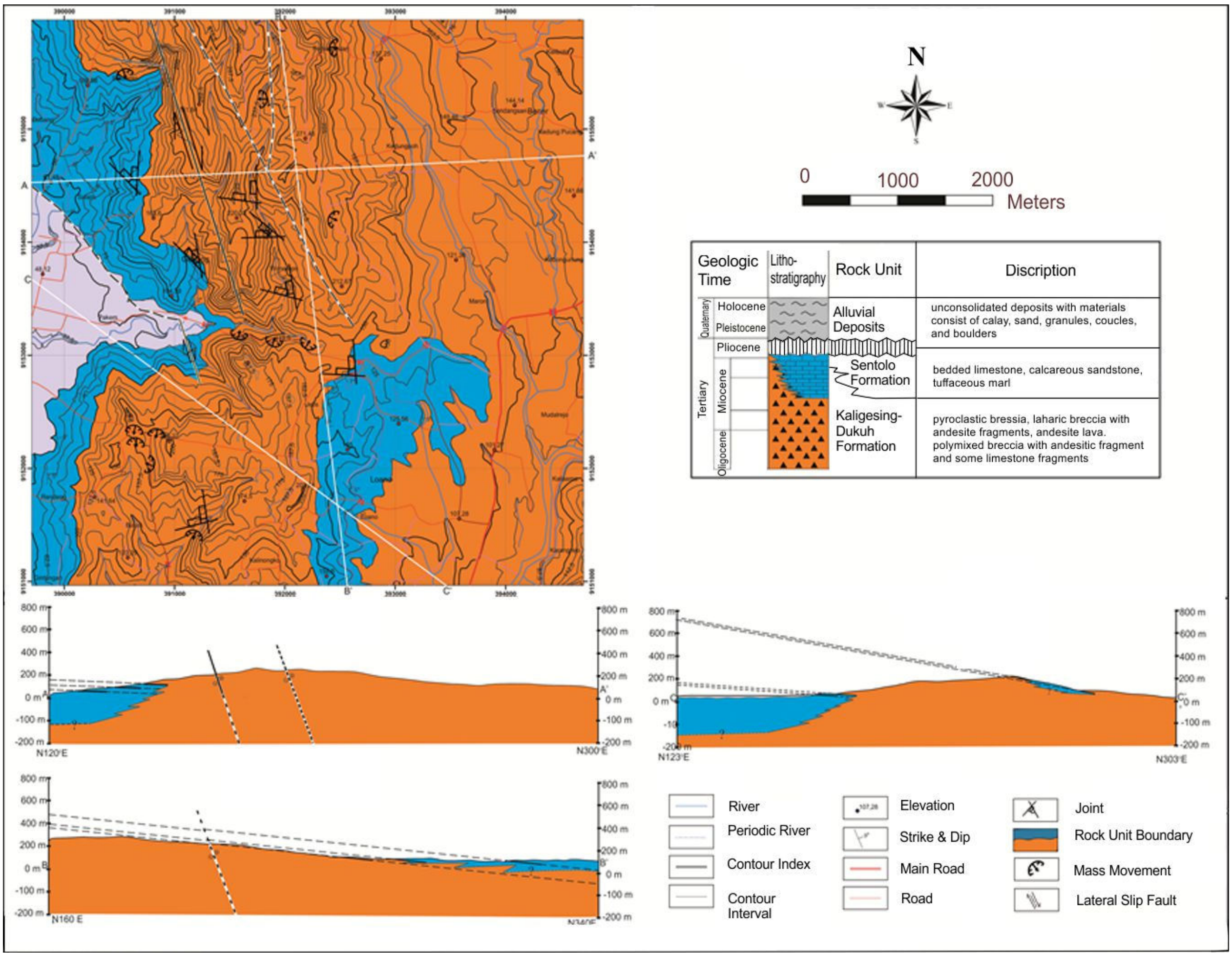

Fig. 4 The geologic map of the study area.

On a slope there is a force system that works naturally. Mass movement occurs because of the balance disruption between resisting force and driving force on a slope [10-12]. Slopes consisting of soil or weathered rocks have a susceptibility to mass movements that are different from slopes arranged by fresh and hard rocks [11]. The slopes occupied by soil are strongly influenced by the shear strength of the soil, while the slopes compiled by rocks in general are influenced by rock shear strength, and also the presence of geological structures in that location [12]. The force system model that works on the slope can be seen in Fig. 5.

The factors that cause landslides are passive factors and active factors. Passive factors include topography, geological conditions, hydrological conditions, soil conditions, previous landslides, and vegetation conditions. Active factors that affect land landslides include human activities and climate, especially rainfall [13].

The most of mass movements in the research area that is physiographically included in the Kulon Progo Zone or Menoreh Hill, generally can be classified as soil slides or landslides. Weak layer that often acts as the plane of failure is the boundary between fresh rock and weathered rocks [13]. Landslides in this area generally move with high speed in combination with flowing as happened in Kemanukan, Panusupan, and Ngelo villages, Purwodadi (Fig. 6). Meanwhile the most dominant factor influencing landslide occurrence is slope inclination that is classified into steep. Map showing slope distribution of the study area is figured as Fig. 7.

Basic physical and mechanical properties of soil and rock of the study area were obtained by triaxial and direct shear tests. The results are then processed using slide v.6 software for determining the safety factors. The results of the identification and analysis of soil movements in the study area are detailed in Table 2.

To create a landslide-prone zone, the authors refer to the Regulation of Minister of Public Works of the Republic of Indonesia Number 22/PRT/M/2007. Distribution of landslide potential zones is carried out with different levels of vulnerability, based on seven aspects that cause soil movements, including slope inclination, soil conditions, slope constituent rocks, rainfall, water condition, seismicity, and vegetation. Based on those seven natural physical aspects, the landslide potential zone of such an area can be divided into 3 (three) types [14], as follows:

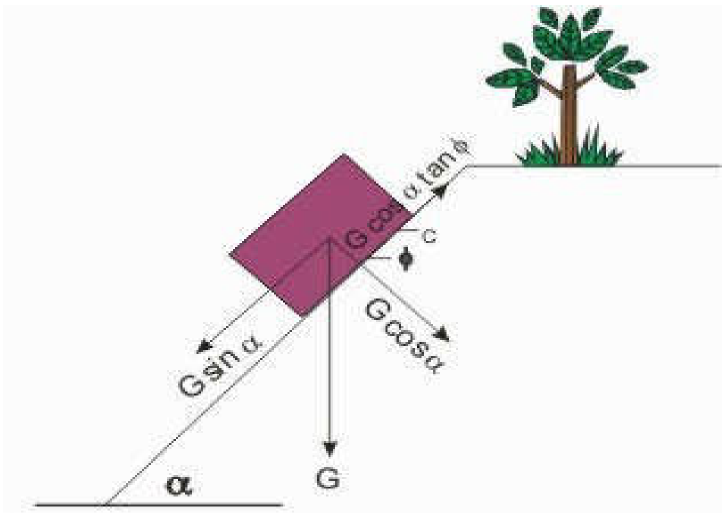

Fig. 5 The distribution of stresses on a slope [3].

G = weight force; α = slope inclination; Φ = friction angle of rock mass and the sliding plane; c = cohesion force.

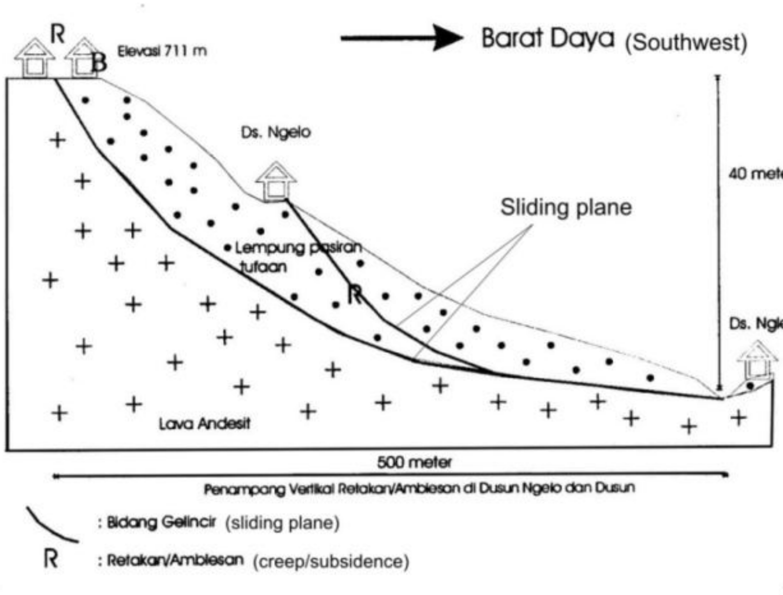

Fig. 6 Typology of land movement at Ngelo and Purwodadi Areas [7].

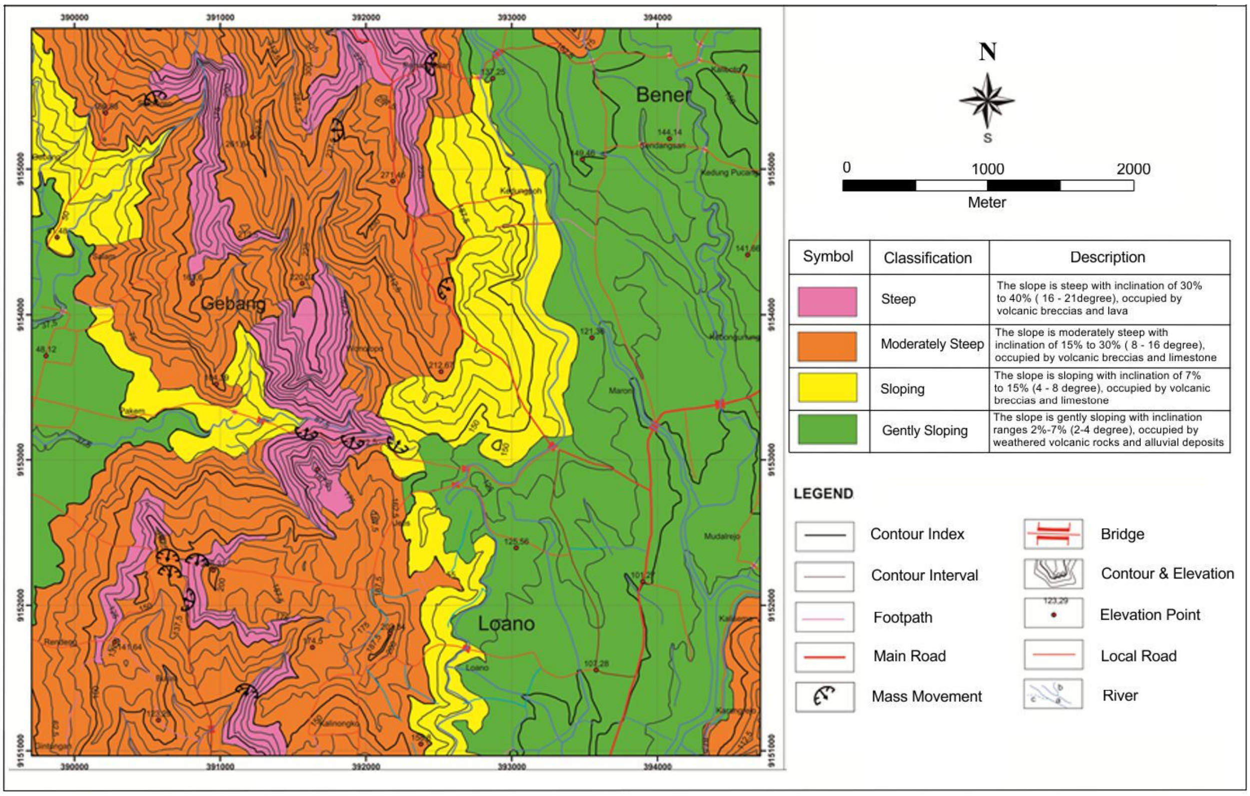

Fig. 7 Map of slope distribution.

Table 2 Results of slope stability analyses in the study area.

No.	Location/village	Environmental description	Lithology	Type and direction of the movement	Value of FS & classification
1	Panungkulan	The slope is positioned on a volcanic ridge, moderately steep	Soil of volcanic breccia weathering	Type: earth slide East-Southeast direction	0.517-0.6 Unstable
2	Wonotopo	The slope is positioned on a volcanic ridge, moderately steep	Soil of volcanic breccia weathering	Type: earth slide Southeast direction	0.59-0.6 Unstable
3	Bulus	The slope is positioned on a volcanic ridge, moderately steep	Soil of volcanic breccia weathering	Type: debris slide West direction	0.66-0.7 Unstable
4	Bulus	The slope is situated on a eroded-denudated volcanic hills, moderately steep	Soil of volcanic breccia weathering	Type: debris slide West direction;	0.82-0.9 Unstable
5	Jetis	The slope is situated on a eroded-denudated volcanic hills, moderately steep	Soil of volcanic breccia weathering	Type: earth slide West direction	0.68-0.74 Unstable
6	Sidoleren	The slope is positioned on a volcanic ridge, classified as steep slope	Soil of volcanic breccia weathering	Type: earth slide South direction	0.94-1.02 Critical

- Landslide Potential Zone of Type A: The zone is situated on mountain slopes, hilly slopes, and river cliffs with a slope of more than 40%.
- Landslide Potential Zone of Type B: The zone is situated on mountain foot area, hillfoots, and river cliffs with slope ranges from 21% to 40%.
- Landslide Potential Zone of Type C: The zone is situated on highland, lowland, plains, river cliffs, or river valleys with slope ranges from 0% to 20%.

Referring to the zoning and indicators mentioned above, the research area can be divided into two zones, namely landslide potential zone of type B and landslide potential zone of type C (Fig. 8).

✓ Landslide Potential Zone of Type B: This zone is in volcanic hill units and volcanic ridge units, homoclyne valleys, where the slope ranges 20%-40%. The study areas are the villages of Sidoleren, Wonotopo, Bulus and Penungkulan. Area examines about 40%.

✓ Landslide Potential Zone of Type C: The zone is in volcanic hills, denuded volcanic plains, and alluvial plains, where the slope ranges 0%-20%. The area in the area is around 60%.

The classification of landslide potential zones based on the level of vulnerability is as follows [12] (Table 3).

3.3 Landslide Vulnerability

The three types of landslide potential zones (type A, type B, and type C) are able to show vulnerability levels varying from high to low, depending on the slope conditions, rock/soil constituents, geological structure, water saturation, rainfall, and landuse. Each indicator is given a vulnerability rating weight (Table 4).

Assessment on the vulnerability of landslide potential zone is done through the sum of the weighted weight values of 7 (seven) indicators on the natural physical aspects. The total value ranges from 1.00 to 3.00 whereas to determine the vulnerability level of the zone, the following criteria are used (Table 5).

Based on the analysis mentioned above, overlying seven maps of the indicators (slope distribution map, soil distribution map, geologic map, railfall intencity, water condition, seismicity, and vegetation map) of the study area, the landslide potential zone of type B can be divided into high vulnerability and moderate vulnerability, while the landslide potential zone of type C can be be sorted for high vulnerability and low vulnerability. Details of the description of landslide potential zoning and vulnerability in the study area are writen in Table 6, whereas the map of the vulnerability is presented in Fig. 9.

3.4 Landslide Causing Factors

The occurrence of mass movements in the study area and its surroundings is influenced by the following factors:

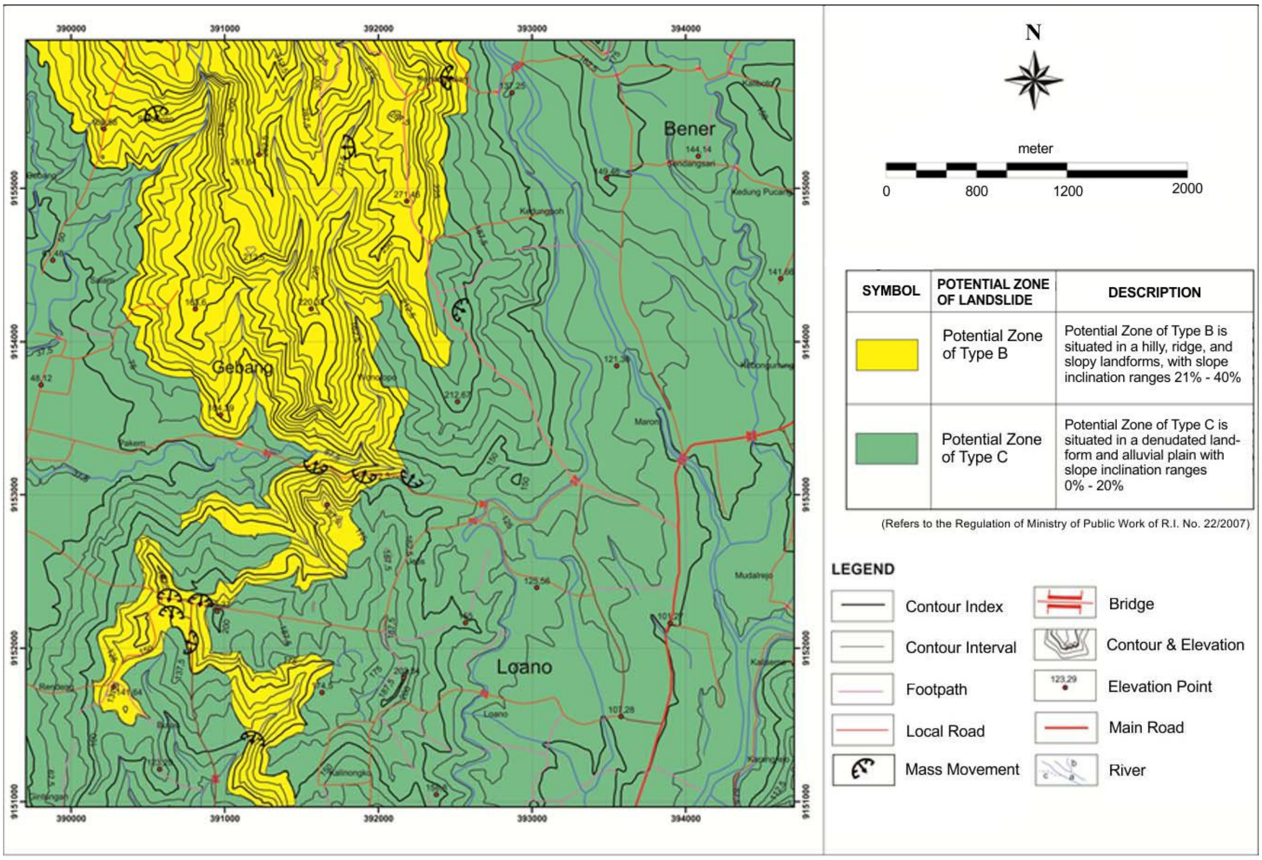

Fig. 8 Map of landslide Potential Zones, Wonotopo and Surrounding Area.

Table 3 Indicators for landslide vulnerability zones.

Indicator	Weight percentage
Slope inclination	30%
Soil condition	15%
Rock forming the slope	20%
Rainfall	15%
Slope drainage	7%
Seismicity	3%
Vegetation	10%

Table 4 Weight and indicator of vulnerability level.

Weight	Indicator
3	High capacity to cause landslide
2	Moderate capacity to cause landslide
1	Low capacity to cause landslide

Table 5 Total Score of vulnerability level of the landslide potential zone.

Vulnerability of the landslide potential zone	Total score of the weighted weight
High	2.40-3.00
Moderate	1.70-2.39
Low	1.00-1.69

Table 6 Landslide potential zones and their vulnerability of the study area.

Type	Level of vulnerability	Lithology and environmental condition	Involving areas	Recommendations
B	High	Volcanic breccia, weathering is quite high, geological structures present	Sidoleren, Wonotopo, Penungkulan, and Bulus villages	Not for development and settlements, application of good water drainage system, tap rooted trees plantation, reducing tree logging
	Moderate	Volcanic breccia, weathering is quite high, geological structure present	Sidoleren, Wonotopo, Penungkulan and Bulus villages	Application of good water drainage system, tap rooted trees plantation, reducing tree logging
C	High	Bedded limestone and volcanic breccia that have medium to high weathering rates	Salam, Rendeng, Bulus, Kalinongko, Jetis and Kedungpoh villages	Not for development and settlements, application of good water drainage system, tap rooted trees plantation, reducing tree logging
	Low	Alluvial and breccia, gentle slope to relatively flat, land use: rice fields, farming, and settlements	Maron, Mudalrejo, Kedung Pucang, Sendangsari, and Pakem villages	There is no land movement, so construction of public facilities and settlements is recommended to be located in this area.

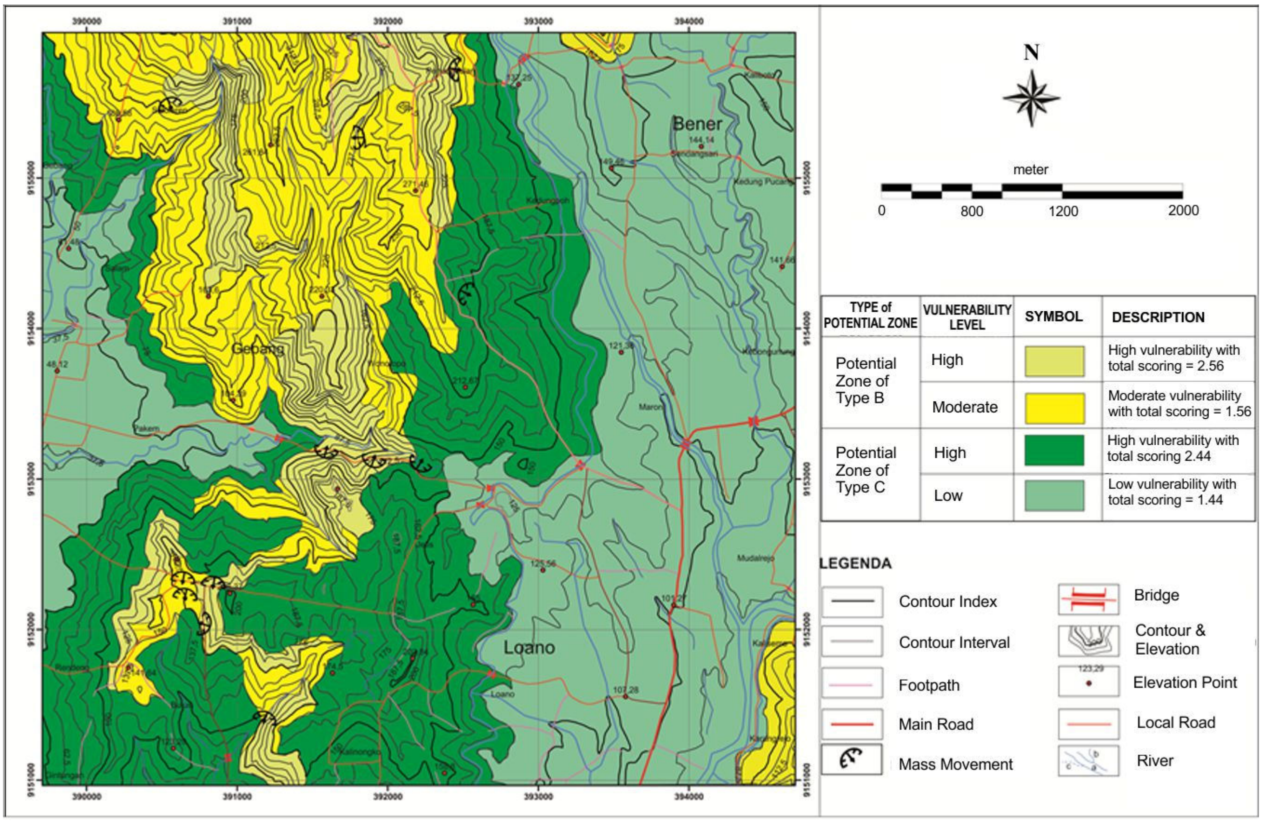

Fig. 9 The landslide vulnerability map of Wonotopo and Surrounding Area.

(1) Slope inclination. The movement of soil in the study area generally occurs on a moderately steep slope up to a steep, with angle of 15^o-35^o, weathering process and high erosion on the bedrock, and reinforced by the presence of geologic structures such as joints, cracks, fissures, or faults.

(2) Soil conditions. The thicker the soil that covers the slope, the more loose and easier it is to pass water, the more it triggers ground movement.

(3) Slope constituent rocks. Slope stability is influenced by the physical/mechanical properties of soil/rock constituent slopes, especially the internal friction angle. If the value of the friction angle of the material is large, then the material will be more

resistant to receiving the external stress imposed on it. The friction angle of soil in the research area is generally small, ranging 5^o-23^o.

(4) Rainfall. High rainfall intensity increases the process of infiltrating water into the soil, uprising the water content, ultimately increasing pore pressure and decreasing the value of soil/rock cohesion, so that soil movements are easier to occur. In the research area the highest rainfall occurs in November-January. Water content in soil samples ranged from 31.64%-78.66%. The greater the water contents in the body of the slope, the greater the pore pressure, so the potential for ground movement is greater.

(5) Geological structure. For example landslide which occurs in Sidoleren Village, is influenced by the presence of horizontal faults, with the direction of landslides relative to the south on the foot wall of the fault. Avalanches in Bulus village are influenced by the presence of very dense joints, with the type of rock fall. The direction of land movement is ranging from 17^o N-198^o E, relative to the south-southwest.

4. Mitigation

The followings are slope stabilization recommendations in the study area as the structural mitigation:

4.1 Structural Mitigation

4.1.1 Decrease the Driving Force

- Change the slope geometry by reducing slope height, making terraces, or reducing the slope angle so that it is more gently sloping.
- Controlling surface water can be done by making surface channels with orientation conformable to contour lines. It is effective to prevent waterlogging during the rainy season, and to prevent erosion on the slope surface.

4.1.2 Increase the Resisting Force

Construct retaining walls, used to resist ground movements while protecting buildings from collapse. The retaining wall must be completed with horizontal drainages, to flow water out from the body of the soil. At the bottom of the retaining wall, water channels should be made.

4.2 Nonstructural Mitigation

For nonstructural mitigation, community empowerment needs to be developed, for example by socializing and increasing their understanding on landslide risk reduction. It can be done through formal and non-formal education. Formal education needs to provide disaster mitigation subjects in the school curriculum. Meanwhile in nonformal education, training on disaster risk reduction and preparedness needs to be carried out for village officials and local communities.

5. Conclusions

From results of the assessment, analysis, and discussion in this paper, it can be concluded that:

(1) The geomorphology of Bener district areas is undulating and hilly with slope gradients ranging from steep (30%-70% or 16^o-35^o), moderately steep (15%-30% or 16^o-35^o), sloping (7%-15% or 4^o-8^o), and gently sloping (2%-7% or 2^o-4^o). The pattern of developing river flows is rectangular, dendritic, and sub-dendritic.

(2) The lithological stratigraphic sequence starting from the oldest to the youngest consists of Kaligesing Volcanic Breccia formation, formed from the Late Oligocene to the Early Miocene, overlain by Sentolo Limestone formation of Early Miocene to Pliocene, and the alluvial deposits of Holocene. There are relatively dense joints and a lateral slip fault with Northwest-Southeast strike.

(3) Landslide potential zones can be divided into 2 types, namely type B and C. Type B landslide potential zones consist of high vulnerability and moderate vulnerability. Meanwhile the potentially landslide type C zone consists of high vulnerability and low vulnerability.

(4) Such structural and nonstructural mitigation

needs to be developed in the study area to prevent landslide disaster. The structural mitigations are such as lowering the slope height by terracering, reducing slope angle, and constructing retaining wall with horizontal drainage, while nonstructural mitigation can be done by involving disaster mitigation subject in the curriculum, socialization, and training on disaster risk reduction and preparedness for village officials and local communities.

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