Study On Slope Stability In Vulnerable Landslide Area For Evaluation Of General City Spatial Arrangement Plan In South Balikpapan

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Abstrak

Morfologi Balikpapan dicirikan oleh topografi perbukitan dan sedikit dataran, dengan kemiringan lereng berkisar 8% sampai lebih dari 40%. Hasil penelitian lapangan, pengujian laboratorium dan pemodelan komputer menunjukan daerah rentan gerakan tanah di Balikpapan Selatan mempunyai nilai faktor keamanan pada daerah rentan gerakan tanah secara keseluruhan berkisar antara 0,52 - 1,94.
Hasil tumpang tindih Peta Rentan Gerakan Tanah dengan Rencana Umum Tata Ruang Kota (RUTRK) menunjukan beberapa bagian perencanaan yang overlap antara zona rentan tinggi gerakan tanah dengan rencana pemukiman perkotaan, kawasan jasa perdagangan, jalan arteri primer dan rencana jalan kolektor primer. Diperlukan rencana mitigasi gerakan tanah, baik dengan pengendalian lereng atau langkah lainnya untuk mengurangi dampak yang akan muncul.
Kata Kunci : Perbukitan, Faktor Keamanan, Tata Ruang

Abstrak

Morphology of Balikpapan is characterized by hilly topography and little bit plane topography, with slope value between 8% up to more than 40%. Result of field research, laboratory test and computer modelling showing the high susceptible landslide zone has safety factor between 0,52 – 1,94.
Overlay of Susceptible Landslide Zone Map and General City Spatial Plan shows several parts of plan such as city housing area, prime artery road and prime collector road overlap with high susceptible landslide zone. Planning of mitigation of landslide through slope stabilisation or other effort to reduce the possible impact.
Key Word : Hilly Topography, Safety Factor, Spatial Arrangement.

1. Introduction

1.1. Problem Background

Considering how important landslide information is for road networking plan, dam, housing, city development and mitigation efforts of landslide disaster, the central government issued Decree of Minister of Minerals Resource and Energy No.1452 K/10/MEM/2000 about Technical Guidance of Government Duty in Inventory of Energy and Mineral Resource, Geological Mapping and Vulnerable Landslide Zone Mapping.

Local or City Government should take landslide potency of the area into consideration in city development policy, in order to reduce both economic and other risks.

1.2. Study Objective

This research is aimed to study landslide and to identify the susceptible landslide area in South Balikpapan, considering this area is the center of city activities.

And the purpose of this is making landslide vulnerable zone maps and assessing slopes stability in order to give evaluation for existing General City Spatial Arrangement Plan of South.

1.3. Statement of the Problem

According to the geological condition, morphology and geotechnical aspect of the soils, and other factors, it is necessary to determine susceptible landslide zone. By such knowledge, control and mitigation of landslide disaster is able to be planned. With the formulated problem as follow: 1) Where is the vulnerable landslide area located and How is its failure potency according to Factor of Safety (FOS) analysis?, 2) How is the relevancies of the existing General City Spatial Arrangement

Plan according to vulnerable landslide zone map?, and 3) What kind of suitable slope stabilization method or landslide controlling method should be applied in such case?.

2. Literature Review

2.1. Mass Movement

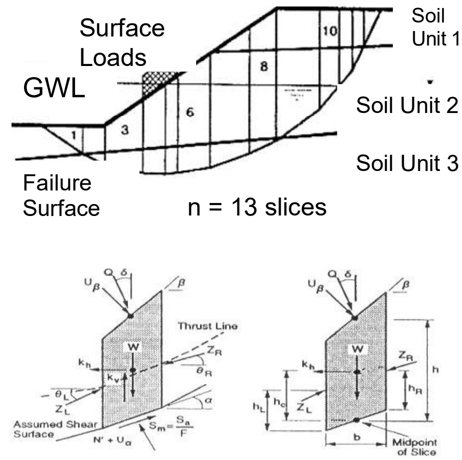
Mass movement may take place as a result of a shear failure along a given internal surface or when general decrease in effective stress between particles causes full or partial liquefaction (Whitlow. R, 1983).

Soil mass movement is a geologic process as a result of interaction of some conditions such as morphology, geology, structural geology, hydrogeology, and land use. Those conditions affect each other and create slope condition, which tends to move or failure (Karnawati 2002 in BAPEKOINDA DIY, 2002).

Many factors that could lead soil mass movement or rock slope failure generally interacting each other and they are not independent. According to Abramson et al, 1996, factors, that should be understand because they affect slope stability; a) Geological condition, b) Site topography, c) Possible Effects of Proposed Construction, d) Material properties, e) Groundwater Condition, and f) Seismicity.

2.2. Slope Stability Analysis

When the landslide has circular type that commonly takes place in the soft soil or fractured rock, method of slices procedure is able to be used in its slope stability analysis (See Figure 1.1). All limit equilibrium methods for slope stability analysis divide a slide mass into *n* smaller slices. There are many methods of slices, thus can be applied in slope stability analysis, two of them are Simplified Bishop and Spencer Methods. Simplified Bishop Method Bishop (1955) assumes that all interslice shear forces are zero, reducing the number of unknown by (*n-1*). This method satisfies vertical force equilibrium for each slice and overall moment equilibrium about the center of the circular trial surface.



F = factor of safety
S_a = C + N' tan ϕ
S_m = mobilized strength
U_α = pore water force
U_β = surface water force
W = weight of slice
N' = effective normal force
Q = external surcharge
k_v = vertical seismic coefficient
k_h = horizontal seismic
Z_L = left interslice force
Z_R = right interslice force
θ_L = left interslice force angle
θ_R = right interslice force angle
h_L = height to force Z_L
h_R = height to force Z_R
α = inclination of slice base
β = inclination of slice to
b = with of slice
h = average height of slice
h_c = height to centroid of slice

Figure 1.1. Division of Potential sliding mass into slices and Forces acting on a typical slice (Abramson et al, 1996)

The simplified Bishop also assumes zero interslice shear force. The overall moment equilibrium of the forces acting on each slice is given by

$$\Sigma M_o = \sum_{i=1}^{n}[W(1-k_v)+U_\beta + Q\cos\delta]R\sin\alpha - \sum_{i=1}^{n}[U_\beta \sin\beta + Q\sin\delta](R\cos\alpha - h)$$

$$-\sum_{i=1}^{n}[S_m]R + \sum_{i=1}^{n}[k_h W(R\cos\alpha - h_c)] = 0 \quad (2.1)$$

Where

R = radius of the circular failure surface.
h = average height of slice.
h_c = vertical height between center of the base slice and centroid of the slice.

This method assumes Resultant interslice forces are horizontal (i.e., there are no interslice shear forces). If the factor safety is assumed to be the same for all slices, substitute the Mohr-Coulomb criterion to equation 2.1 to give

$$F = \frac{\Sigma_{i=1}^{n} (C + N' \tan\phi)}{\Sigma_{i=1}^{n} A_5 - \Sigma_{i=1}^{n} A_6 + \Sigma_{i=1}^{n} A_7}$$

(2.2)

Where :

$A_5 = [W(1-k_v) + U_\beta \cos\beta + Q \cos\delta] \sin\alpha$

$A_6 = [U_\beta \sin\beta + Q \sin\delta](\cos\alpha - \frac{h}{R})$

$A_7 = k_h W(\cos\alpha - \frac{h_c}{R})$

Next, forces are summed in the vertical direction for each slice.

$$F = \frac{C \sin\alpha}{[W(1-kv)] - U_\alpha \cos\alpha + U_\beta \cos\beta + Q\cos\delta - (m_\alpha x N')}$$

(2.3)

Where m_α is given by

$$m_\alpha = \cos\alpha \left[1 + \frac{\tan\alpha \tan\phi}{F} \right]$$

(2.4)

Spencer Method (1967, 1973, 1981) uses two equations to solve safety factor, F, and the angle interslice forces, θ. θ is assumed to be constant for each slice. This method was also used and extended by Wright (1969, 1974). Summation of parallel and vertical force to the base of slice is given by

$$S_m = W \sin\alpha + (Z_R - Z_L) \cos(\theta - \alpha)$$

(2.5)

$$N = W \cos\alpha + (Z_R - Z_L) \sin(\theta - \alpha)$$

(2.6)

From Mohr-Coulomb theory

$$S_m = \frac{cb.\sec\alpha + N \tan\phi}{F}$$

(1.7)

Substitutes equation 2.7 into equation 2.5

$$\frac{cb.\sec\alpha + N \tan\phi}{F} = W \sin\alpha + (Z_R - Z_L) \cos(\theta - \alpha) \quad (2.8)$$

Removes N from equation 3.6 and equation 2.8 and solves to Z_R

$$Z_R = Z_L + \frac{cb.\sec\alpha - FW \sin\alpha + W \cos\alpha \tan\phi}{\cos(\theta - \alpha)[F - \tan(\theta - \alpha) \tan\iota]}$$

(2.9)

Total of forces moment which act on the base of slice

$$Z_L \cos\theta (h_L - \frac{b}{2} \tan\alpha) + Z_L \sin\theta \left(\frac{b}{2}\right) + Z_R \sin\alpha \left(\frac{b}{2}\right) = Z_R \cos\alpha (h_R + \frac{b}{2} \tan\alpha \quad (2.10)$$

Solved equation 3.10 for h_R

$$h_R = \left(\frac{Z_L}{Z_R}\right) h_L + \frac{b}{2} (\tan\theta - \tan\alpha) \left(1 + \frac{Z_L}{Z_R}\right) \quad (2.11)$$

The first slice's condition is bounded by Z_L and h_L bounds the last slice. In many cases such values are zero. By assuming value of parameter F and θ and known Z_L and h_R limit, therefore it is capable to apply equation 2.9 and 2.9 and 2.11 repeatedly, from slice to slice and evaluate Z_L and h_L of the last slice. Then value of Z_R and h_R at the boundary is compared with the resulted value. Adjustment is made to determine V and θ value, this procedure is repeated and iteration is stopped when value of Z_L and h_L is in the acceptable tolerance according to the known Z_L and h_L value at the margin. This method is determined statically having has unknown of 3 n.

2.3. The Level of Landslides Vulnerability

According to the Decision of Minister of Minerals resource and Energy No.1452 K/10/MEM/2000 Level of vulnerability of landslides can be classified according to safety factor . Where FOS < 1,2 High Susceptible, 1,2 -1,7 Moderate Susceptible, 1,7 - 2,0 Low Susceptible and FOS > 2,0 Safe/Stabil.

2.4. Slope Stabilization Methods

Slope stabilization methods generally reduce driving forces, increase resisting forces, or both. Driving force can be reduced by excavation of material from the appropriate part of the unstable ground and drainage of water to reduce the hydrostatic pressures acting on the unstable zone. According to Abramson et al (1996), Resisting forces can be increased by; a) Drainage to increases the shear strength of the ground, b) Eliminating of weak strata of other potential failure zones, c) Building of retaining structure or other supports, d) Provision of in situ reinforcement of the ground, e) Chemical treatment to increase shear strength of the ground.

3. Research Method

Desk Study and Collection of Existing Data: This research is initiated by literatures review and collecting the available secondary data from many institutions and the result of prior research in that area.

Field Research: Field research is aimed to obtain primary data and collect samples as input in slope stability analysis.

Laboratory Test: Some of the data are obtained from laboratory tests of soil (direct shear, attenberg limit, etc).

Overlaying Maps to Delineate Susceptible Landslide Area: Spatial aspect data that have already been obtained such as; geological map, morphological map, topographic map, land use map etc, are overlaid by GIS to determine the susceptible landslide area.

Mathematically and Graphically Data Processing: The Susceptible landslide zone map as qualitative data will be completed with factor of safety (FOS) from some representative location. Simplified Bishop and Spencer-Wright Method are employed in the FOS calculation. Computer program GALENA 3.1. was employed to solve the mathematical and graphical problem of slope stability with input both of the field measurement and laboratory test result such as; slope geometry, hydrogeology, internal friction angle (ϕ), cohesion (c), soil density (γ) and plasticity index (PI).

General Spatial Arrangement City Plan Evaluation: After the Susceptible Landslide Zone Map has been finished and completed with quantitative analysis, then it is overlaid with the existing General City Spatial Arrangement Plan of Balikpapan City. Such overlaying will give information about the part of General City Spatial Arrangement Plan that overlap with High Susceptible Land Slide Area.

Drawing Conclusion Based on Analysis and Evaluation: In the end of the research, conclusions will be withdrawn based on the analysis of both the primary data and secondary data analysis. This conclusion is also made based on the Evaluation of Balikpapan General City Spatial Arrangement Plan.

4. Research's Results

Geomorphology and Topography of the research area is characterized by hill slopes and flatted area with elevation between 0 – 103 m from sea level. Morphometrically, the slopes in the research area can be classified into very gentle slope up to strong steep slope which have value between 0 – 40%. Geomorphology of the research area can be divided into 3 geomorphic unit, those are:

- Alluvial Plane Unit (± 15%)
- Weakly Dissected Undulated Hilly Geomorphic Unit (± 30%)
- Moderately Dissected Undulated Hilly Geomorphic Unit (± 55%)

Stratigraphy of the research area from older to younger formation that consists of Balikpapan Formation, Kampung baru Formation and Recent Alluvial deposits.

Balikpapan Formation consists of less consolidated or cohesionless quartz sands with quartz contents almost reach 90%, and in several places (Semayang seaports and Babi island) found consolidated quartz sandstone, cemented by iron oxide with frequent cross bedding as sedimentary structure. Quartz sandstone with inter bedded coal, shale and claystone are found in the East parts of the area such as Sepinggan, Gunung Bahagia and its vicinity. This formation was deposited in terrestrial environment, deltaic shallow marine transition facies (Moss and Chamber, 1998)

Kampung Baru Formation lies conformingly on and different facies with Balikpapan Formation, is consisted of claystone, shale, siltstone, coal and sandstone, generally dominated by monotonous thick claystone with very rare bedding. It has the widest extension in the research area, especially in the central and North part. That covers West Balikpapan District, North Balikpapan District, Central Balikpapan District and East Balikpapan District. This formation was deposited in shallow marine, Deltaic marine facies (Moss dan Chamber, 1998).

Alluvial deposits occupy angular-unconformingly on the Balikpapan Formation and Kampung Baru Formation consists of coble, pebble, loose quartz sand and clay material. Those deposits are generally found along east coast of Sepinggan as the result of Sedimentation of the Big Manggar River, the Small Manggar, the River Sepinggan River and the Damai River. The Alluvial deposits are also found in Kariangau Area as the deposition result of the Wain River.

The geological structures of the research area consist of anticline, fault and fractures/joints. The Joint structures consist of shear joints and extension joints (release joints) that are found in Babi island, Behind GOR Petamina, Telaga Sari, and Daksa housing area.

The fault structure is reverse fault that is running parallel to the folding axis. This structure passes long distance involves Daksa housing area, Sepinggan until Kampung Damai. The lateral slip fault is also found in Gunung Sari and Behind the GOR Pertamina with Northwest – Southeast direction.

The fold structure is an anticline that has Northeast – Southwest axis direction, therefore the existing bedding planes dips of rocks commonly have to the Southeastward and Northwestward direction.

The hydrogeology condition of that area is characterized by confined aquifers with various depths, for instant in Gunung Sari Area has aquifer with 155 m depth, in Teritip with 44 m depth, in Manggar Area 147 m depth and in Damai village 52 m depth. But in several places of the research area has been found many springs such as Stal Kuda, Gunung Bakaran and Semayang Seaports. Such springs are interpreted as the result of perched aquifer that has intersected topography. The existence of this perched aquifer is caused by impermeable lens of claystone layers in the thick quartz sandstones of Balikpapan Formation, therefore it can stop the water infiltrates deep down and store it as shallower groundwater and sometimes seepages on the surface as spring.

Through maps Overlaying such as slope map, geological map, geological potency map, land use map and other data using Map GIS Software was resulted Susceptible Landslide Zone Map.

Undisturbed soil sampling was done use tube of PVC pipe closed tightly by plastics seals in order to avoid physical and mechanical properties change. This sampling was aimed to carry out laboratory test which represent the field condition.

Measurement of slopes geometry involves the angle of slope, height of slope and slope length. The result of measurement is shown in the Table 4.1

Table 4.1
Angle of slope, slope length and slope height as result of EDM measurement

Coordinates *UTM 50*		Soil	Angle	Slope Length	Slope Height
0488 144	9861 825	Sandy Clay	α_1 : 29° 5’ 30” α_2 : 24 30’ 10”	15 m 33 m	16.06 m
0486 378	9862 808	Sandy clay	α_1 : 32° 20’ 5” α_2 : 30° 15’ 40”	12 m 12m	12.46 m
0483 392	9861 994	Sandy clay	α_1 : 25° 32’ 15”	18 m	8.07 m
0487 489	9864 019	Sandy clay	α_1 : 23° 30’ 45” α_2 : 15° 20’ 15”	11 m 30 m	12.32 m
0487 732	9862 146	Clay	α_1 : 18° 42’ 15”	32 m	10.26 m
0487 349	9860 228	Clay	α_1 : 90° α_2 : 22° 30’ 0”	3 m 7 m	5.64 m
0481 151	9860 086	Quartz sand	α_1 : 35° 12’ 5”	23 m	13.26 m
0481 334	9860 643	Clay Shale	α_1 : 59° 55’ 45” α_2 : 44° 48’ 15”	7. m 9 m	12.40 m
0484 435	9859 464	Quartz sand	α_1 : 27° 1’ 5”	26 m	11.81 m
0480 314	9859 549	Loose sand	α_1 : 22° 34’ 50”	60 m	23.03 m
0486 378	9862 808	Sandy clay	α_1 : 30° 16’ 45”	22 m	11.09 m

The laboratory tests were carried out to determine mechanical and physical properties of soils such as; density (γ), plasticity (PI) as result the subtraction liquid limit and plastic limit, cohesion (c), and internal friction angle (ϕ).The tests results of 13 soil samples are shown in the table 4.2

Table 4.2
The Results of Laboratory tests

Sample Number	Density (gr/cm^2)			PI (%)	) kg/cm^2	I (ϕ)°
	γu	γw	γd			
/TS/BPN	1,92	2,24	1,44	5.2	0,25	16
/TS/BPN	1,60	2,16	1,40	5.2	0,22	18
/TS/BPN	1,79	2,33	1,44	5.6	0,22	12
/TS/BPN	1,60	1,92	1,44	6.5	0,24	17
/TS/BPN	1,92	2,24	1,44	30.3	0,25	16
/TS/BPN	1,92	2,92	1,52	25.4	0,17	13
/TS/BPN	1,52	1,74	1,15	-	0,02	42
/TS/BPN	1,52	1,74	1,15	-	0,02	47
/TS/BPN-a	1,36	1,52	1,08	-	0,04	23
/TS/BPN-b	1,60	2,32	1,20	8.2	0,20	18
/TS/BPN	1,52	1,74	1,15	-	0,02	38
/TS/BPN-a	1,27	1,36	1,11	-	0,03	25
/TS/BPN-b	1,92	1,23	1,40	7.0	0,25	16

The Computer modeling of 11 locations were able to give critical factor of safety (FOS) and illustrations of their failure surfaces. The outputs of the computer modeling are the illustration of failure surface and factor of safety (FOS), those are written in the Table 4.3.

Table 4.3
FOS values (by GALENA version 3.10)

Locations	***Bhishop***	***Spencer***
Kol. Syarifudin Yos street, Beside Bethany Church,	1.15	1.15
Ruhuy Rahayu street, Beside Taxation office	1.34	1.34
Road S. Ampal BalikPapan Baru Housing Area	1.18	1.18
Infront of Polda Balikpapan	1.94	1.86
Kol Syarifudin Yos street, beside fuel pump station	1.88	1.89
Marsma R. Iswahyudi street RT. 70 Gunung Bahagia	1.64	1.64
Telaga Sari RT 39/011	1.04	1.04
Mekar Sari RT 19/RW006	0.52	0.55
Jend. Sudirman street, Stal Kuda	1.06	1.06
Telaga Sari RT 007/002	1.53	1.53
Behind of KPP Taxation office	1.37	1.35

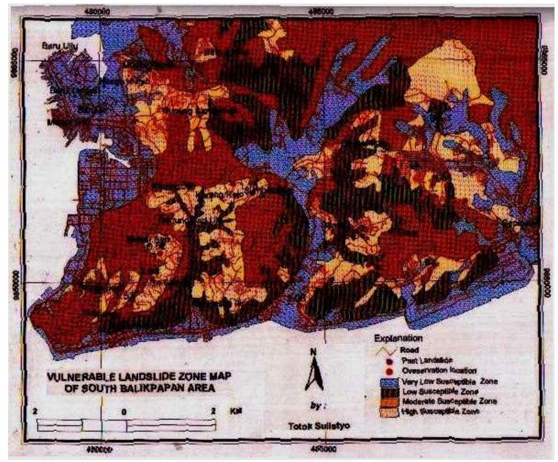


Figure 4.1. Susceptible Landslide Map of South Balikpapan.

The result of overlay high susceptible landslide zone and General City Spatial Arrangement Plan overlay shows there are several parts of the plan are jeopardized by potential landslide hazard. Such plan parts involve city housing area in Prapatan, Telaga Sari, Mekar Sari, Gunung Sari, Karang Jati, Karang Rejo, Gunung Bahagia, Kampung Damai, Sepinggan and others. High susceptible landslide zone is also cover road plan, primary collector road plan and artery road such as Kol. Syarifudin Yos Street, Gunung Samarinda, Sukarno-Hatta Street in Batuampar area, Jend. Sudirman and Marsma R. Iswahyudi Street.

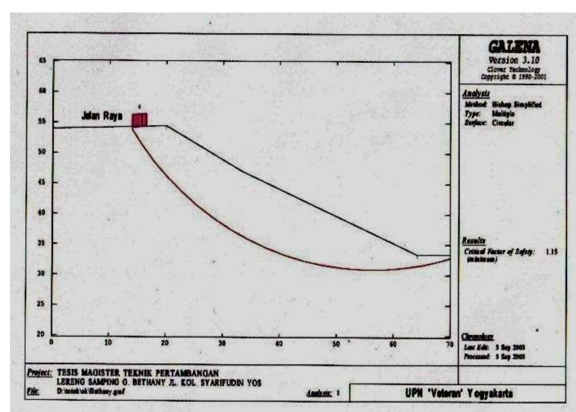


Figure 4.2. Analysis of Kol. Syarifudin Yos Street's slope (beside of Bethany Church) by GALENA 3.10

The typical landslide in the research area is sliding with circular failure surface.

Such condition of existing mass movement took place in the soft soil slope, which has very low uniaxial compression strength $0.02 – 0.25\ kg/cm^2$ or 1.9 – 24.5 kPa those less than 700 kPa (Beniawski, 1973 dan ISRM, 1979).

5. Discussion

Balikpapan is located closed to the equatorial line and has tropical climate, has yearly rainy season, in the long run such condition has been accelerating weathering process of slope forming material. Such processes cause reducing material cohesion and fragmentation of rock/soil forming minerals, decrease internal friction angle (ϕ) of rock/soils. High precipitation rate also increases soil moisture content therefore it also increases soil unit weight (γ) and total weigh of slope material. Pores water as a result of infiltration of rain water will give hydrostatic pressure to the soil grain so it will reduce normal stress (σ-u) and decrease shear strength (τ) of soils. This condition is agravated by geologic formation where deposited in deltaic environment with less cementation and compaction.

6. Conclusion & Recommendation

High Susceptible Landslide Zone in South Balikpapan is the area with slope more than 40%, less vegetation cover, consist of clay and soft sandstone and loose quartz sand. Its jeopardize housing area, road and othe infrastucture. Some place characterize with symptoms such as tension crack and sporadic subsidence. Safety factor slope of this area between 0,52 – 1,94.

Recommendation: a) Routinely Monitoring of Slopestability should be held, as a prevention and mitigation of landslide hazard, b) Revision of City Spatial Arrangement Plan should be done by taking into account of landslide risk. C) Replace Conventional stabilization slope with proper stabilization method.

Special Remark

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