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The Slopeslides Potential Modeling Of Semarang City Roads

Vinsensius Priyo Wicaksono[a,]*, Pratikso[a], Rinda Karlinasari[a]

Master of Civil Engineering, Sultan Agung Islamic University, Semarang, Indonesia.
Jl. Kaligawe Raya Street Km.4, Semarang, Central Java 50112 ; PO Box 1054/SM

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ABSTRAK

Tujuan penelitian ini adalah untuk mengetahui parameter yang mempengaruhi dan penyebab dominan longsor lereng pada ruas-ruas jalan di wilayah Kota Semarang; dan untuk mengetahui pemodelan potensi risiko longsor lereng pada ruas-ruas jalan di Wilayah Kota Semarang. Penelitian deskriptif kuantitatif ini mengambil metode pengambilan data sekunder, identifikasi faktor penyebab longsor, pengamatan kondisi lapangan dan pengolahan data spasial. Pendataan stabilitas lereng untuk mendapatkan database lereng jalan dan pemilihan ruas jalan pada kondisi "sangat rawan longsor" dari peta Ancaman Longsor Lereng hasil olahan data spasial, dipilih 3 dari 43 ruas, yaitu Jl. Kyai Mojo I, Banyumanik, Jl. Mr. Abdul Madjid Djojoadiningrat, Banyumanik dan Jl. Gombel Lama, Banyumanik. Dari Peta Topografi, didapat ketiga ruas berada pada sudut lereng 25% hingga diatas 40%. Dari Peta Geologi, ketiga ruas berada dalam zona Formasi Kerek dan Kaligetas. Dari Peta Jenis Tanah, ketiga ruas berada pada daerah dengan jenis tanah lempung pasiran berkerikil. Dari olahan data curah hujan selama 10 tahun dari 6 pos pengamatan hujan didapat ruas-ruas berada pada zona curah hujan sedang pada pemodelan intensitas hujan kala ulang 2, 5, 10 dan 25 tahun. Analisis stabilitas lereng menggunakan pemodelan elemen hingga 2D dari data pengambilan sampel tanah di lapangan yang mendapatkan modifikasi menjadi dua kondisi, yaitu kondisi kering dengan parameter hasil pengujian tanah pada laboratorium. Pemodelan kondisi jenuh berupa asumsi beban curah hujan pada lereng dan kondisi *soil suction*. Perbedaan hasil cukup signifikan pada SF antara kedua kondisi membuktikan tingkat curah hujan berpengaruh terhadap stabilitas meskipun pemodelan tersebut belum dapat mewakili kondisi seluruh lereng.

Kata kunci: Data spasial; Elemen hingga; Jalan Kota Semarang; Longsor; Pemodelan lereng

E-MAIL

Vinsensius.p.w@gmail.com*
mts@unissula.ac.id

ABSTRACT

The purpose of this study was to determine influencing parameters and dominant causes of roads-slope failures, and to determine the potential risk of roads-slope failures modeling in the Semarang City Region. This quantitative descriptive research uses primary an secondary data collection methods, identification of factors that cause landslides, observation of field conditions and processing of spatial data. Slope stability data collection to obtain a database of road slopes and selection of road sections in "very prone to landslides" conditions from the Slope Hazard Map processed by spatial data, 3 out of 43 sections were selected, are Jl. Kyai Mojo I, Jl. Mr. Abdul Madjid Djojoadiningrat, and Jl. Gombel Lama. It is not a coincidence that they were at the same zone and types according from the Topographic Map, the Geological Map, and from the Soil Type Map. From the processed rainfall data for 10 years from 6 rain observation posts, it was found that these sections are in the moderate rainfall zone in the modeling of rainfall intensity for return periods of 2, 5, 10 and 25 years. Slope stability analysis uses 2D finite element modeling from soil sampling data in the field which is modified into unsaturated conditions with parameters according to the results of soil investigations and saturated conditions with an assumptions on rainfall loads on slopes and soil suction. The significant difference in the SF results between conditions proves that the rainfall affects the stability, even though the model cannot represent all slopes condition.

Keywords: *Finite element; landslide; Semarang City roads; Slope modelling; Spatial data*

I. INTRODUCTION

Landslides and floods are natural phenomena that often occur in Indonesia, one of which is in the city of Semarang. Landslide events are generally triggered by internal factors such as slope topography and physical and clinical properties of rocks (lithology) as well as external triggering factors such as high levels of rainfall, earthquakes and human intervention with changes in land use and so on [1]. In the southern part of Semarang City, there is a thrust fault which is a stretch of fault on the island of Java from the Kendeng Mountains, East Java Province to Bogor, West Java Province which is cut by a horizontal fault, one of which is the Kaligarang Fault [2] from north to south. It was recorded that in 1856 the city of Semarang was rocked by a major earthquake, but it never happened until now, so even though the trigger factor for landslides in the form of earthquakes is very small, this cannot be ignored [3,4].

By taking into account the geological and topographical conditions of each area in the Semarang City area, landslide risk modeling can be carried out, and most importantly preventive measures as an initial measure to anticipate landslides whose impacts can result in property, economic and logistical losses, damage to the environment and even victims soul [5].

Limitation of this research is to modeling the risk of landslides that have the potential to occur on roads in the city of Semarang as a preventive measure to ensure traffic safety for road users. Based on the background of the problems above, the formulation of the research problem can be drawn, namely, "How to model the potential for slope failures on roads in the city of Semarang?" The formulation of the problem raises research questions, namely the influencing parameters and the dominant causes of slope failures on roads in the city of Semarang; and modeling the potential risk of slope failures on roads in the Semarang City Region..

II. METHODOLOGY

2.1 Research Location

The location and boundaries of the study area for this research are the slopes on the roads within the administrative area of Semarang City, Central Java Province. Map of the administrative area of Semarang City.*Similarity*

2.2 Assessment and Weighting of Slope Landslide Risk

Analysis and mapping of the area is needed as a monitoring and observation of slope phenomena for potential landslides to get an overview of the real conditions for the level of potential vulnerability to landslides and the factors that cause them. A map of the distribution of landslide hazard levels and the causal factors, can be formulated for inspection and maintenance efforts and activities so that slope stability can be achieved.

2.3 Analysis of Landslide Hazard Mapping

The main analysis tool in this research is scoring or weighting. Weighting is intended as a score for each class on each parameter. Giving this score is based on the influence of the class on landslides. The higher the effect on landslides, the higher the score given, and vice versa.

2.4 Class Weighting

The weighting of the class elements that affect the occurrence of landslides depends on slope, soil type, rainfall, land use and geology, therefore to be overlayed with ArcMap softwae to make Landslide Threat Map. Landslide Threat class with the score, overlayed with the slope, mass movement and Landslide Risk, making Slope Slide Analysis Map.

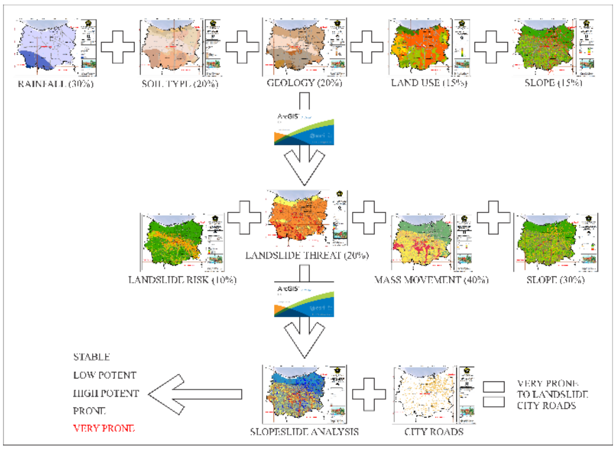

Figure 1. The illustration of the spatial data analys to make Slopeslide Analysis Map (source: author's data processing)

2.5 Determination of Road Sections in Research

Of the 1,012 roads with Semarang City Road status, not all of them are located in geographical and topographical conditions with slopes and cliffs. So from the results of overlaying the road sections on the slope parameters, ground motion, risk and threat of landslides that produce a range of values in each area by buffering the road sections.

Furthermore, this research will focus on three road sections in conditions that are highly prone to landslides, with the consideration that if all road sections are selected in conditions that are highly prone to landslides or all city roads in each landslide condition will take a very long time in this study.

2.6 Soil Investigation and Laboratory Testing

Ideally, after the road sections studied have been selected and determined in this study obtained, soil investigation activities will be carried out. However, in this study secondary data will be used from the results of soil investigations on these road sections which have been carried out by taking samples according to applicable standards.

The soil sample that has been taken is brought to the testing laboratory to determine the index and soil properties, in the form of an index size to determine the classification, consistency and density of the soil, the tests of which are: water content, unit weight, specific gravity, atterberg limits, and grain size analysis. The magnitude of the soil property is in the form of: triaxial compression test unconsolidated undrained (uu), triaxial compression test consolidated undrained (cu), and consolidated test.

2.7 Calculation of Rainfall Intensity

Rainfall intensity is the value of the height of rainfall that occurs per unit of time where rainwater is concentrated in a certain area. Duration is the amount of time the rain occurs. The correlation between rainfall intensity and duration is that in general high rainfall intensity takes place in a short duration over a large area. It is very rare that there is a combination of high rainfall intensity and long duration. Several methods of calculating rainfall intensity with Mononobe method, which rainfall intensity can be determined through the following equation.

$$I = \frac{R_{24}}{24} \cdot \left(\frac{24}{t_c}\right)^{2/3} \qquad (1)$$

I is rain intensty (mm/hr);
tc is the duration of the rain (hr);
R24 is rainfall in 24 hours (mm/day)

2.8 Rainfall Stabilities Method

The method used to obtain the value of groundwater infiltration is called the Green-Ampt Method, namely the approach of providing a clear boundary between the soil with a certain humidity at the bottom and the saturated soil above it. The method proposed by Li Chen and Michael Young (Chen & Young, 2006) is by calculating the total value of water infiltration before it is inundated on the soil surface where a series of equations can produce a value for the thickness of saturated soil.

$$Z_f = \frac{F(t)}{(\theta_s - \theta_i)} \qquad (2)$$

Zf is the thickness of saturated soil (cm);
F(t) is the cummulative of the infiltration (cm);
θs is saturated soil water content (%);
θi is initial soil moisture (%).

The saturated model used soil suction, that defined as the state where the soil under reduced pressure that measured in terms of the coulmn water height which suspended inside the soil. In this study, soil suction assumed by zero materials cohesion (c = 0).

2.9 Load Assumptions

The loading assuming of slope stability in this study is used in the form of vehicle loads according to the function of the road from Indonesia Public Works Department. The traffic load will be determined based on the research location that will be selected later. The placement of traffic loading is adjusted to the road sections according to the existing geometric. The rain load from the Green-Ampt method above is assumed to be the thickness of saturated soil (Zf) on the body of the slope.

2.10 Numerical Modelling

Numerical analysis used as the basis for modeling in this study is axysimetry 15-nodes in PLAXIS 2D software version 8.6. The cross section of the road with a slope that is modeled using the cross section of the road from field measurements. Soil data as a material parameter used in the model is taken from the results of soil tests in the field and in the laboratory. The load used is modeled as the traffic load on the road segment.

The finite element method is used in this modeling by not assuming a landslide plane, but looking for the value of the Safety Factor(SF) from the weak plane of the subsoil structure that has been searched for. SF is obtained by gradually reducing the cohesion value c and the internal shear angle until the soil collapses (soil body collapse) using the "phi/c reduction" mode.

III. RESULT AND DISCUSSION

3.1 Analysis of Landslide Hazard Data

The landslide threat category is divided into five categories, namely Very Low Landslide Threat, which is only 0.0023% or 0.89 ha of the total administrative area of Semarang City. Low Landslide Threat of 1% or an area of 288.29 ha of the total administrative area of Semarang City. Moderate landslide threat of 12.45% or an area of 4,832.98 ha; High Landslide Threat of 77.95% or an area of 30,254.49 ha and Very High Landslide Threat of 8.59% or an area of 3,333.75 ha of the total administrative area of Semarang City.

Table 1. Landslide threat categories percentage

Landslide Threat Categories	Administrative area (%)	Study area (%)
Very low	0,0023	0,02
Low	1,00	0,25
Medium	12,45	3,28
High	77,95	11,35
Very high	8,59	9,02

(source: author’s data processing)

Analysis of Slope Landslide Data on City Roads

Spatial analysis of Slope Landslide is an analysis of the parameters of slope slope, ground movement, landslide risk and previous landslide threats.

From this analysis, the results obtained were that 27.31% or an area of 10,132.99 ha of areas in Semarang City were included in the category of Not Potential for Landslide, 29.81% or an area of 11,059.70 ha of areas in Semarang City were included in the category of Less Potentially Prone. Landslides, 26.51% or an area of 9,836.95 ha of areas in Semarang City that fall into the Potential Landslide Hazard category, 13.77% or an area of 5,110.39 ha, and 2.59% or an area of 959.85 ha in the category of Very Hazardous Landslide.

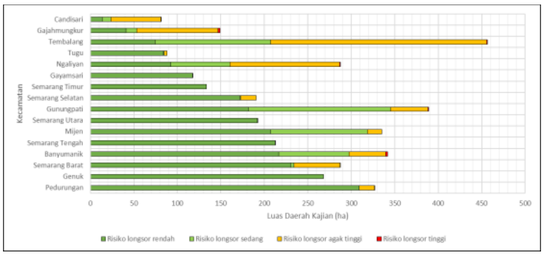

Figure 1. Slopeslide analysis each district
(source: author’s data processing)

Table 2. Slope landslide analysis categories percentage

Slopeslide Analysis Categories	Administrative area (%)	Study area (%)
Stable	27,31	12,81
Low potent	29,81	13,28
High potent	26,51	8,77
Prone	13,77	4,22
Very prone	2,59	1,68

(source: author’s data processing)

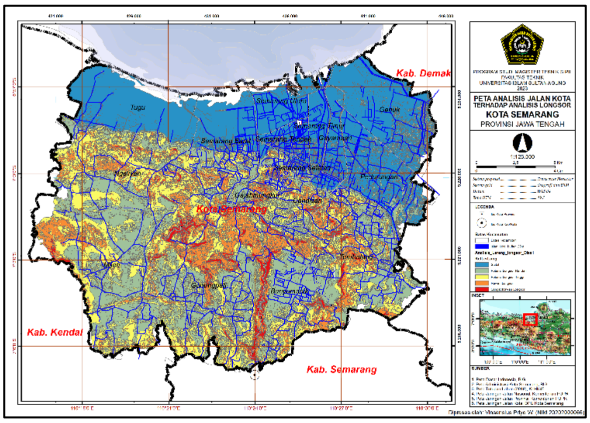

Figure 2. Slopeslide analysis map includes city roads map
(source: author’s data processing)

3.2 Selection of Road Sections

The selection of road sections that are used as research objects and further studies is determined from several aspects, including the highest landslide susceptibility in an area, the similarity of engineering geological conditions, the existing geometric conditions for potential slope landslides, the results of field observations at that location in the form of a history of slope failure events. and the condition of the slopes against potential disasters.

Based on these aspects, three road segments were selected as research objects, materials for review and studies towards validating slope failure analysis, are Jl. Kyai Mojo I, Jl. Mr. Abdul Madjid Djojoadiningrat and Jl. Gombel Lama, both are in Banyumanik District of Semarang.

(a)

Figure 3. The layout of the selected segment roads used in this study followed by the slopeslide evidence at Jl. Kyai Mojo I, Banyumanik District (source: author's data processing)

3.3 Rainfall Analysis

This study uses daily maximum rainfall (R_{24}/R_{MAX}) data for a 10-year period from 2013 to 2022 from observations at the Plumbon Rain Post, Ngaliyan District; Dam Simongan Rain Post, South Semarang District; Jinunjung Irrigation Area Rain Post, Gunungpati District; and Karangroto Weir Rain Post, Genuk District. Use of daily rainfall data for a 10-year period from 2010 to 2019 on observations at the Madukoro Rain Post, West Semarang District; and at the Pucanggading Rain Post, Demak Regency.

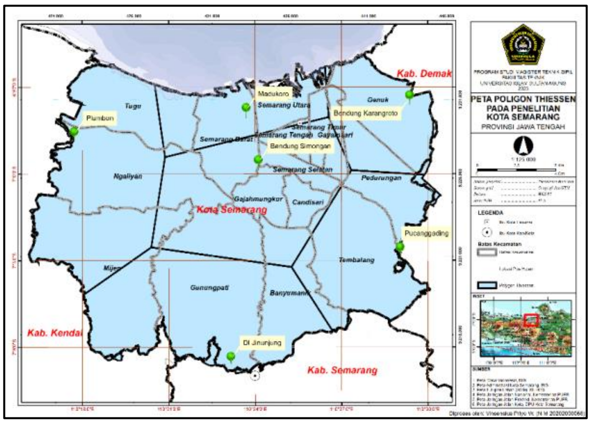

Figure 4. Thiessen Polygon at the study area (source: author's data processing)

The determination of runoff discharge and planned flood is carried out by calculating the probability of maximum rainfall in the area of influence of the study. This calculation uses the basis of the polygon method, which determines the area of the study area and determines the roads and rain stations that affect these roads.

The amount of average rainfall in the area is determined using the Thiessen method, namely by calculating the area and influence of each rain station. Thiessen Polygon analysis is assisted using ArcGIS software.

3.4 Rain Distribution Statistical Parameters

From the calculation of the statistical parameters that have been carried out above, filtering and selection of the type of frequency distribution that will be used with a comparison of requirements is carried out, the results of the analysis of statistical parameters of rainfall are selected using the Pearson Type III Log Distribution Method because the results of these calculations have a value of Slope Coefficient (Cs). and the Kurtosis Coefficient (Ck) meets the requirements.

3.5 Goodness of Fit Test

From goodness of fit test with chi square and Smirnov Komlogorov test, give a result that the data had normal distribution.

3.6 Analysis of Planned Rainfall

The design rainfall data used is data that has been proven to have a normal distribution according to goodness of fit with the Chi-Square and Smirnov-Kolmogorov methods, namely from Pearson III Log data. The design rainfall calculation is the antilog of the sum of the average log rainfall and the k value of the Pearson Log Distribution multiplied by the standard deviation.

From the results of the study it can be interpreted that the greatest possibility of rainfall is in the north to the middle part of the dividing from the east to west side of Semarang City, while in the middle to south part of the west to east side of Semarang City will have lower rainfall. Summary of data analysis of rainfall data and rain intensity as well as design discharge at six rain observation posts in a two to 25 year return period analysis.

3.7 Analysis of Rainfall on the Slope Landslide Study Road Section

The results of the analysis of the planned rainfall intensity that have been processed into a rainfall intensity map for each return period through the software as presented above, are cut to the selected road segment buffer to obtain the area of the planned rainfall intensity segment for the 5 and 10 year return periods.

The rain intensity data can later be compared with slope data that is very prone to landslides and further analysis can be carried out in the form of the effect of rainfall intensity on the slope conditions which are very prone to landslides that have been selected in this study.

3.8 Slope Stability Analysis

It is known that the largest area of soil types in the city of Semarang is sandstone, sandy loam, and gravelly sandy clay. The soil structure, in addition to having a depth of solid soil or hard layers that are not too deep, also has a high potential for landslides to occur because the constituent structures are sand and clay. According to the history of slope failures on the study road section, most of them were landslides of the collapse type which carried material in the form of sand, soil and rock directly from the top of the landslide crown. This avalanche causes the scattering of material around the avalanche point.

The potential for slope avalanches from the soil structure making up the slopes is supported by the geological conditions in Semarang City, namely there are faults and faults, especially on the Jl. Kyai Mojo I and Jl. Gombel Lama. In addition to the potential for slope failures, the road sections studied in this study also have the potential for slip planes at certain depths if examined further in terms of soil surface stability, water seepage and faults. The three previously selected road sections were searched for soil data and field and laboratory tests to carry out slope stability analysis modeling using the two-dimensional finite element method (2D finite elements).

3.9 Load Assumption

In this study a live traffic load of 10 kN/m^2 is given to the road segment, and in the second condition a rainfall load is given with the assumption that the thickness of the soil is saturated (Zf) on the body of the slope according to the Green-Ampt Method.

3.10 Slope Stability Analysis

From the soil parameter data that has been obtained, 2D modeling is carried out to obtain slope stability on the Jl. Kyai Mojo I, Jl. Mr. Abdul Madjid Djojoadinongrat and Jl. Gombel Lama using Plaxis 2D software as shown.

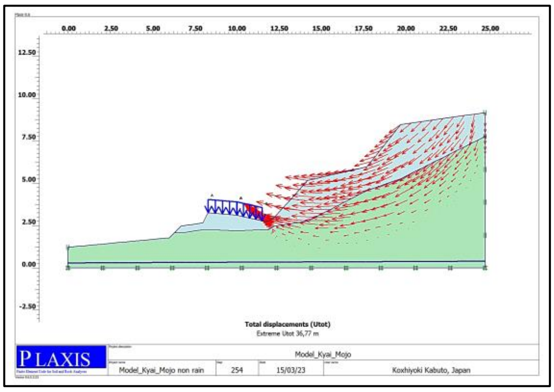

Figure 5. Total displacement of the unsaturated finite element Jl. Kyai Mojo I, Banyumanik District modelling, (source: author's data processing)

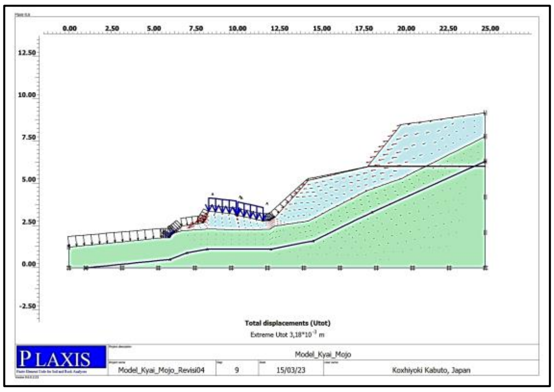

Figure 6. Total displacement of the saturated finite element Jl. Kyai Mojo I, Banyumanik District modelling. (source: author's data processing)

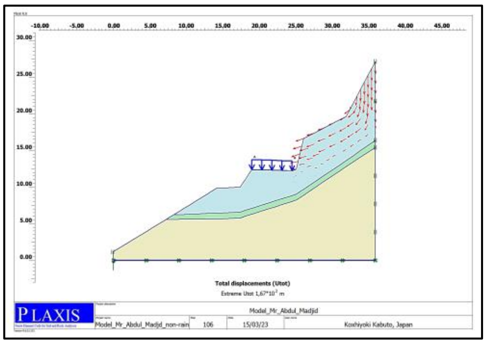

Figure 7. Total displacement of the unsaturated finite element Jl. Mr. Abdul Madjid Djojoadiningrat, Banyumanik District modelling (source: author's data processing)

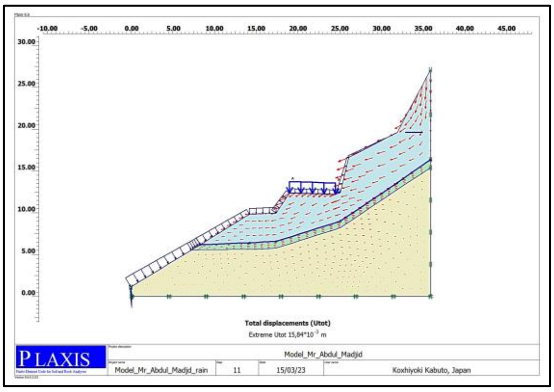

Figure 8. Total displacement of the saturated finite element Jl. Mr. Abdul Madjid Djojoadiningrat, Banyumanik District modelling. (source: author's data processing)

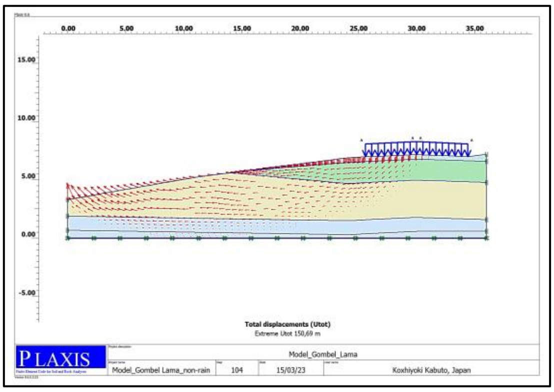

Figure 9. Total displacement of the unsaturated finite element Jl. Gombel Lama, Banyumanik District modelling. (source: author's data processing)

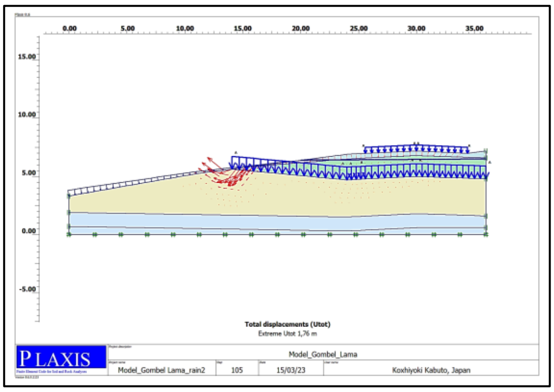

Figure 10. Total displacement of the saturated finite element Jl. Gombel Lama, Banyumanik District modelling. (source: author's data processing)

IV. CONCLUSION

The results of this study can answer the first research question, namely the parameters that influence slope failures on roads in the Semarang City area, namely rainfall factors, soil type factors, geological factors, land use factors and slope slope factors which combine to become a landslide threat. The results of this combination are combined again with the slope factor, ground motion factor and landslide risk factor, which will get an analysis of the landslide slope in Semarang City against city roads.

The results of this study can answer the second research question, regarding modeling the potential risk of slope failures on roads in the city of Semarang, with the results:

2D finite element modeling was carried out in two conditions, they are unsaturated conditions, which using data from soil investigations; and saturated conditions which ignores the cohesion parameters in the material reflect the soil suction, and assuming a traffic live load of 10 kN/m2.

The modeling results obtained results in the form of a significant reduction in the safety factor between modeling in unsaturated and saturated stage on each segment that was studied. On the Jl. Kyai Mojo I, has a respective yield of 5.633 and 1.00; section Jl. Mr. Abdul Madjid Djojoadiningrat 1.796 and 1.00; and the Jl. Gombel Lama is 8.60 and 5.27. This proves that the rainfall factor has a direct effect on slope stability but it has to take out for further research in the future to define the relation between planned flood discharge in the return periods of 25 years to slope stability.

Future research should be proves the handling suggestions of slope stability modeling according to the Indonesia Public Works Departement to find out which appropriate handling model, safe and can be implemented at each location, either at the same study location or other.

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