Slope Risk Management System on Toll Road: a case study Semarang-Salatiga Section

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Abstract. Landslide is a geohazard event which can be caused by several factor, such as high rainfall intensity, slope geological feature and the slope geometry itself. Tropical wet climate and typical geomorphology of Indonesia derives landslide event as common disaster during the wet season. Nowadays, the paradigm in road slope management has changed to put the Slope as an Asset, like other infrastructure. In this case study, a slope risk management system was created to assist road slope managers in planning periodic monitoring and maintenance. As the building have the BIM System, the slope can also be digitalized as GeoBIM. Based on case studies, this system can be used to inventory and create an electronic database of road slope assets. Furthermore, the road slope assets are assessed and prioritized based on geological hazards and economic consequences. In the end, each slope asset will have routine maintenance schedules, costs, and a historical data of repairs and damage. Therefore, the slope asset can be handled effectively and efficiently.

1 Introduction

Semarang – Solo Toll Road is one of the mountain toll roads in Indonesia. It is located about 200 to 650 above mean sea levels. It has many geological formations which contains many types of rocks from various geological age [1]. The most common rock in the toll road trace is breccia, and the most unique and problematic rocks are claystone and shale structure.

Semarang – Solo toll road experienced geotechnical problem during the construction phase. The unstable clayshale rock caused large landslide on KM 32+000. When the clayshale is exposed to the atmosphere and experienced dry and wet condition, it would be degraded immediately [2]. Another study shows that large landslide is also occurred in 1974 near the high embankment construction on Susukan. The soil investigation on landslide location found thick colluvium soil and expansive clayshale [3].

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Another landslide case occurred in May 2020, at KM 426+000 near Susukan bridge. The landslide event is caused by heavy rainfall during the transition between wet to dry season. According to the investigation, the cut slope is located on tropical residual soil and weathered volcanic tuffaceous breccia. The soil and rock at this location have sensitive characteristics with water interaction [4]. Recent landslide case also occurred on Rest Area KM 429, January 2023, due to heavy rainfall and uncontrolled slope drainage [5].

Landslide is frequent events in Semarang – Solo toll road. The event will cause economic and life loss if it happens on the operational phase. In 2006, Major landslide had been occurred to another toll road, Cipularang Toll Road KM 91. Jasa Marga as the Cipularang operator claimed for at least loss of 5 billion rupiah in one month [6]. A comprehensive risk management is necessary to create effective and efficient mitigation strategy. Slope risk management can be used to calculate the possibility of the slope failure based on landslide characteristics, economic, life and emergency action aspect [7].

The research objective is to propose slope risk management on Semarang – Solo Toll Road. As previously explained, Semarang – Solo Toll Road has many special geological feature and high cut – embankment structure. Firstly, the proposed risk management will consider the vulnerability of the slope. The toll road slope assets will be assessed and rated by considering the geological hazards and economic–life loss consequences. The final output of the proposed risk management to provide maintenance and mitigation strategy in accordance with Slope Risk Rating.

2 Research Method

Firstly, the research method was started with field inspection of the slope. The aim of the inspection was to collect the slope geometry (height, wide, and drainage configuration), geological feature (rock or soil type), and actual condition of the slope (vegetation and groundwater flow). Moreover, the inspection also collected the infrastructure and the economic activity around the slope. After that, the research would be continued to rate and prioritize vulnerability of the slope. The mitigation and maintenance strategy would be arranged in accordance with the Slope risk rating.

2.1 Slope Location

The slope location was located on Semarang Solo Toll Road KM 441 to KM 444, near Bawen Interchange. The location had 10 cut slopes and 3 embankment slopes as listed on **Table 1**.

Table 1. List of Slope for the Proposed Slope Risk Management

No	Slope ID	Location	Coordinates
1	SP_18 B	KM 441+800 B	S: 439576, E: 9200360
2	SP_18 A	KM 441+800 A	S: 439476, E: 9200592
3	SP_19 B	KM 442+600 B	S: 0439490, E:9200053
4	SP_19 A	KM 442+600 A	S: 439655, E: 9200079
5	SP_20 A	KM 442+800 A (exit toll)	S: 439383, E: 9199928
6	SP_20B	KM 442+800 B (exit toll)	S: 439326, E: 9199849
7	SP_21 A	KM 442+400 A	S: 439798, E: 9199995
8	SP_22 A	KM 442+800 A	S: 439875, E: 9199803
9	SP_22 B	KM 442+800 B	S: 439875, E: 9199803
10	SP_23 A	KM 443+600 A	S: 440032, E: 9199336
11	SP_23 B	KM 443+600 B	S: 440009, E: 9199174

No	Slope ID	Location	Coordinates
12	SP_24 A	KM 444+200 A	S: 440080, E: 9198852
13	SP_24 B	KM 444+200 B	S: 440137, E: 9198292

2.2 Risk Rating Method

The Hongkong Geo-guide highlighted three important activities on slope risk management: (a) hazard identification, (b) risk mitigation strategy and (c) management of residual risk [8]. The hazard identification for risk rating method for this research is conducted based on Slope Management and Risk Tracking System (SMART). The system could be adopted because the similarity condition between Indonesia dan Malaysia. The variable of SMART was listed on **Table 2** as follows. The risk rating could be presented in GIS Slope Hazard as single database for slope mitigation and maintenance planning [9].

Table 2. Parameter for Slope hazard identification [10].

No	Slope Parameter	Range of Classes	Values
1	Slope Height	Slope with heigth 0 to 200 meters	0 to 200
2	Slope Inclination	Slope with angle 0 to 90 degrees	0 to 90
3	Slope Appearance	Simple	1
		Planar	2
		Asymmetrical	3
		Compound	4
4	Horizontal Alignment	Convex	1
		Concav	2
		Sraight	3
5	Cutting Topography	Top	1
		Middle	2
		Base	3
		Basin/Flat Ground	4
		Sidelong Embankment	5
6	Slope reinforcement type	None	1
		Crib Wall	2
		Piled Wall	3
		Surface Netting	4
		Soil Nailing	5
		Gabion Wall	6
		Rock Bolts / Stitching	7
		Concrete Wall	8
		Masonary Wall	9
		Others	10
7	Vegetation type on slope surface	Grass	1
		Shrub	2
		Fern	3
		Jungle	4
		Plantation	5
		Agricultural	6
		Others	7
8	Slope surface cover condition	Good (100%)	1
		Average (80 to 100%)	2
		Poor (< 80%)	3

No	Slope Parameter	Range of Classes	Values
9	Rock Outcrop Percentage	0 to 100% of slope area	0 to 100
10	Corestone Boulders	Yes	0
		No	-1
11	Weathering Profile of Rock	Mostly < Grade III	1
		Partly < Grade III and Partly > Grade IV	2
		Mostly Grade IV - Grade VI	3
		Mostly Grade IV - Grade VI plus Corestone Boulders appearance	4
		Mostly Colluvium	5
13	Ground saturation condition	Low	0
		Medium	1
		High	2
		very high	3

2.3 Consequences to Life Category

For the consequences to life category, the determination of parameters should consider the several elements, such as: property near the slope, people who lived near the slope, public facility, telecommunication, electrical network, and road network outside the toll slope. According to the elements, the consequences to life parameters is determined into 4 types of risks as listed on **Table 3**.

Table 3. Parameter for Consequential to life Category [11]

Facilities	Consequence-to-life Catagory
• Heavily Used Building / Public Building (residential building, Hospital, school, market store, power station, bus salter, railway platform and dangerous good storage site) • Road with very heavy vehicular or pedestrian traffic density.	Category 1
• Major infrastructure facility (railway, LRT, flayover, subway and tunnel portal) • Construction site • Road with heavy vehicular of pedestrian traffic density. • Heavily used open space and public waiting area.	Category 2
• Lightly used open-air recreation area • Road with low vehicular or pedestrian traffic density. • Remote Area	Category 3

2.4 Slope Risk Category

SMART system was a slope management which was developed by Public Work Department of Malaysia. The system was suitable for assessing geo-hazard on meta-sediment of claystone, mudstone, sandstone, and siltstone. The geohazard risk category was determined by Instability score, which varied from 0 to 1. The instability score was calculated based on equation (1).

$$Y = 0.027(height) + 0.02(angle) + 0.163(shape) + 0.354(plan_{profile}) + 0.278(cutting) + 0.202(structure) - 0.172(main_{cover}) + 0.472(cover) + 0.017(rock_{exposure}) - 1.266(corestone_{boulders}) + 0.249(rock_{profile}) + 0.281(groundsat) - 4.293 \quad (1)$$

The instability score (Y) was transformed to probability value for qualitative purpose. The transformation equation was listed on **Table 4**. The probability value was used for interpretation the instability level and action determination. The instability level was divided into 5 categories: very low, low, medium, high, and very high, as listed on **Table 5**.

Table 4. Equation for probability calculation [12]

Value of Y	Calculation of probability, P
Y < -2	P = 0.05
-2 < Y < 0.5	P = 0.0037Y3 + 0.0891Y2 + 0.3195Y – 0.3531
0.5 < Y < 4	P = 0.0105Y3 – 0.1275Y2 + 0.5152Y + 0.2952
Y > 4	P = 1

Table 5. Instability Category based on Probability value [12]

Probability, P	Instability Category
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 – 0.6	Medium
0.6 – 0.8	High
0.8 – 1.0	Very High

2.5 Slope Maintenance

The frequency of slope maintenance was determined depend on consequence to life category. For Category 1 and Category 2, it is recommended to conduct routine inspection and maintenance minimum once every year. For Category 3, the recommended frequency was once every two years. For tropical area like Indonesia, it would be wise if the routine inspection scheduling considered the rainfall aspect and the transition between wet and dry season. [11]

3 Research Method

3.1 Risk Rating of Semarang Solo Toll Road

A series of visual inspection have been conducted on 13 slopes as previously mentioned. It is found that 2 slopes are in medium risk, 10 slopes are in high risk, and 1 slope is in very high risk. The medium risk is in the embankment and medium high cut slope. Both of high and very high-risk slope is in clayshale and tuffaceous volcanic breccia area. The risk rating value and detailed slope condition are listed on **Table 6** as follow. The GIS map of slope risk rating as GeoBIM system is shown on **Fig. 1**.

Table 6. The Slope Condition and Risk Rating

No	Slope Id	Location	Slope Geology	Hydrology	P value	IS SMART System
			Hard Rock	Seepage		
1	SP_18A	KM 441 + 800	Shale with interbeded sandstone	None, Rapid Permeability	0.84	Very High
2	SP_19A	KM 442 + 600 (exit tol Bawen)	Breccia	None, Rapid Permeability	0.55	Medium

No	Slope Id	Location	Slope Geology	Hydrology	P value	IS SMART System
			Hard Rock	Seepage		
3	SP_20A	KM 442 + 800 (exit tol Bawen)	Breccia	Slight at toe, moderate Permeability	0.79	High
4	SP_21A	KM 442 + 400	Residual Soil	None, Rapid Permeability	0.53	Medium
5	SP_22A	KM 442 + 800	Breccia	None, Rapid Permeability	0.61	High
6	SP_23A	KM 443 + 600	Residual Soil	Slight at toe, moderate Permeability	0.67	High
7	SP_24A	KM 444 + 200	Breccia	None, Rapid Permeability	0.61	High
8	SP_18B	KM 441 + 800	Shale with interbeded sandstone and quartzite	None, Rapid Permeability	0.66	High
9	SP_19B	KM 442 + 600 (exit tol Bawen)	Shale with interbeded sandstone	None, Rapid Permeability	0.69	High
10	SP_20B	KM 442 + 800 (exit tol Bawen)	Breccia	Slight at toe, moderate Permeability	0.72	High
11	SP_22B	KM 442 + 600	Breccia	Slight at toe, Slow to moderate Permeability	0.64	High
12	SP_23B	KM 443 + 600	Residual Soil	None, Rapid Permeability	0.79	High
13	SP_24B	KM 444 + 200	Breccia	Slight at toe, Slow to moderate Permeability	0.61	High

3.2 Risk Rating of Semarang Solo Toll Road

The consequences to life of Semarang Solo Toll Road in accordance with Table 1 and Table 3, all the slopes are in Category 1 or Category 2. Considering that the toll road is part of National Arteries Roadway, and it has very heavy vehicular, therefor all the slopes are classified as Category 1. Therefore, for the minimum frequency of slope maintenance of all slopes will be once every year.

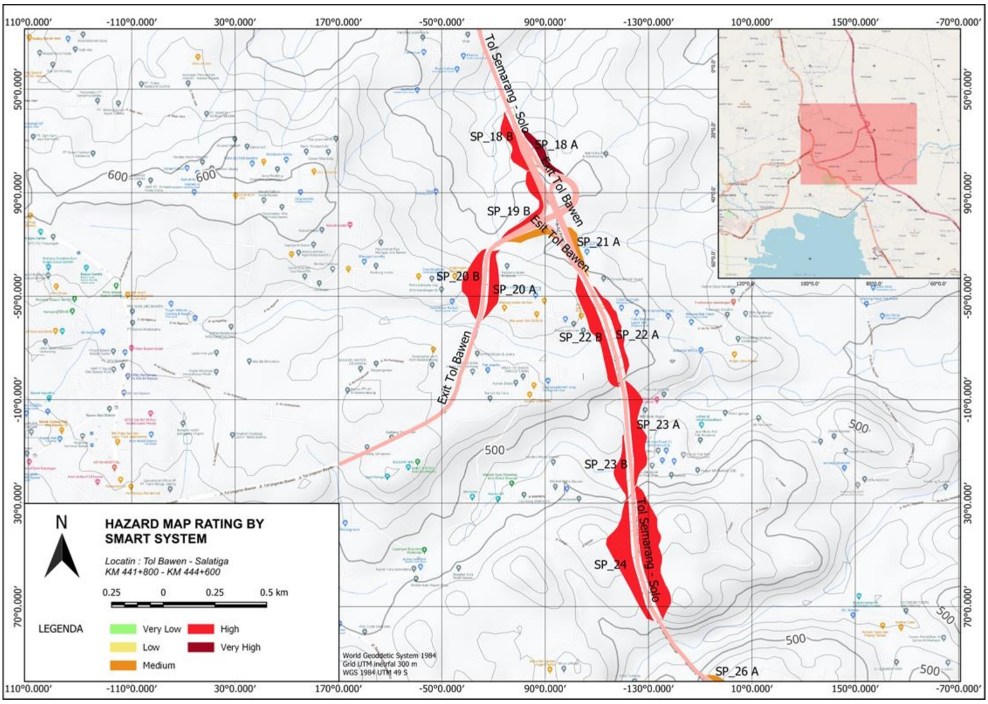

Fig. 1. Hazard map rating of the Semarang – Solo Toll Road slopes

According to the slope inspection, the mitigation and maintenance can be arranged. For light maintenance, the slope may have only routine inspection. Slope maintenance is intended to recover the slope from any deteriorations. Key activities on maintenance consist of drainage line clearing, slope cover clearing, and structural reinforcement repair. The slope maintenance plan is detailed on **Table 7**.

Table 7. The Slope Maintenance Plan

No	Slope Id	Location	Instability by SMART System	Slope Repair	Cost Estimation (In Rp)
1	SP_18A	KM 441 + 800	Very High	Regrading	14,998,231,027.24
2	SP_19A	KM 442 + 600 (exit tol Bawen)	Medium	-	7,551,359.43
3	SP_20A	KM 442 + 800 (exit tol Bawen)	High	Surface Drain and Horizontal Drain	127,877,007.80
4	SP_21A	KM 442 + 400	Medium	-	10,583,887.90
5	SP_22A	KM 442 + 800	High	Horizontal drain and shotcrete	1,457,034,601.60
6	SP_23A	KM 443 + 600	High	Surface Drain and Revegetation	195,427,688.25
7	SP_24A	KM 444 + 200	High	Surface and Horizontal Drain, Shotcrete	1,694,972,810.64
8	SP_18B	KM 441 + 800	High	Surface Drain and Regrading	241,151,424.10

No	Slope Id	Location	Instability by SMART System	Slope Repair	Cost Estimation (In Rp)
9	SP_19B	KM 442 + 600 (exit tol Bawen)	High	Regrading	10,302,340,273.97
10	SP_20B	KM 442 + 800 (exit tol Bawen)	High	Surface and Horizontal Drain, Revegetation	252,165,301.16
11	SP_22B	KM 442 + 600	High	Horizontal drain and shotcrete	252,165,301.16
12	SP_23B	KM 443 + 600	High	Surface Drain	172,457,463.12
13	SP_24B	KM 444 + 200	High	Horizontal drain and shotcrete	2,272,577,584.50

Table 7 shows that some of slopes need to be repaired on the surface and horizontal drained. Surface drainage clogging is the common deteriorations of slope due to bush growth. Moreover, horizontal drainage clogging is one of the causes of slope instability which increases pore water pressure. For Slope no SP_18A, regrading of the slope need to be implemented due to clayshale instability. Based on the instability score on Table 6, it is recommended to maintained Slope SP_18A first. The maintenance sequence is started from greatest IS score to lowest IS score. The Slope_21A will be the last sequence to be maintained.

4 Conclusion

There are two slopes are in medium risk, ten slopes are in high risk, and one slope is in very high risk. According to the consequences to life aspect, all the slopes are included in Category 1. It makes all the slopes need to be inspected and maintained at least once every year. Most of slopes need to be repaired on drainage aspect. Slope Regrading is applied for very high-risk slope with geological consideration. It is possible to make priorities of slope maintenance by using Slope Risk Management system. Furthermore, it is also possible to arrange the cost of slope maintenance for short-term and long-term plan.

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5 References

1. R. Thanden, H. Sumadirdja, P. Richards, K. Sutisna and T. Amin, *Geological Maps of Magelang and Semarang Sheet, Java,* Bandung: Geological Research and Development Center, 1996.
2. I. M. Alatas, S. A. Kamaruddin, R. Nazir, M. Irsyam and A. Himawan, “Shear Strength Degradation Of Semarang Bawen Clay Shale Due To Weathering Process,” *Jurnal Teknologi,* vol. 77, no. 11, pp. 109-118, 2015.
3. Muhrozi and S. Wardani, “Problem of High Embankment on Clay Shale at Semarang-Ungaran Toll Road STA 5 +500 to 6 +300,” in *Geotechnical Engineering for Disaster Mitigation and Rehabilitation and Highway Engineering 2011*, Semarang, 2011.

4. GWA Design Technology, “Laporan Penanganan Longsoran Jalan Tol Semarang Solo KM 426,” GWA Desain Teknologi, Semarang, 2020.
5. Harian Kompas, “Longsor di Rest Area Ungaran Diduga Dipicu Aliran Air Tak Terkendali di Bukit,” Harian Kompas, 01 February 2023. [Online]. Available: https://regional.kompas.com/read/2023/02/01/075338878/longsor-di-rest-area-ungaran-diduga-dipicu-aliran-air-tak-terkendali-di?page=all. [Accessed June 2023].
6. Koran Tempo, “Longsor, Cipularang Rugi 5 Miliar,” Tempo, 25 March 2006. [Online]. Available: https://koran.tempo.co/read/ekonomi-dan-bisnis/67216/longsor-cipularang-rugi-rp-5-miliar. [Accessed 25 June 2023].
7. R. Fell, K. Ho, S. Lacasse and E. Leroi, “A framework for landslide risk assessment and management,” in *PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON LANDSLIDE RISK MANAGEMENT*, Vancouver, 2005.
8. K. Ho and C. Cheung, “Human Fingerprint in Landslide - The Importance of strategic landslide risk management,” in *SCG-XIII INTERNATIONAL SYMPOSIUM ON LANDSLIDE*, Cartanega, 2020.
9. M. Kaamin, A. A. Kadir , N. N. A. Zarin, N. F. A. Ahmad, S. N. M. Razali, S. M. Bukari and M. A. Ahmad, “Hazard And Risk Slope Inventory Using Geographical Information System (GIS): Case Study At Federal Route Simpang Pulai From Section 35 To 45,” in *International Engineering Reaserch and Inovation Symposium*, Melaka, 2016.
10. S. Jamaludin, H. Omar and B. B. Huat, “Evaluation of Slope Assessment Systems for Predicting Landslides of Cut Slopes in Granitic and Meta-sediment Formations,” *American Journal of Environmental Science,* pp. 135-141, 2006.
11. Geotechnocal Engineering Office, Guid to Slope Maintenance, Hong kong: The Gaverment of the Hong Kong Special Administrative Region, 2003.
12. S. Jamaludin and A. N. Hussein, “Landslide hazard and risk assessment: The Malaysian experience,” in *International Association of Engineering Geology*, London, 2006.