Numerical study of slope protected by rockfill and shredded tyre mixture gabion wall

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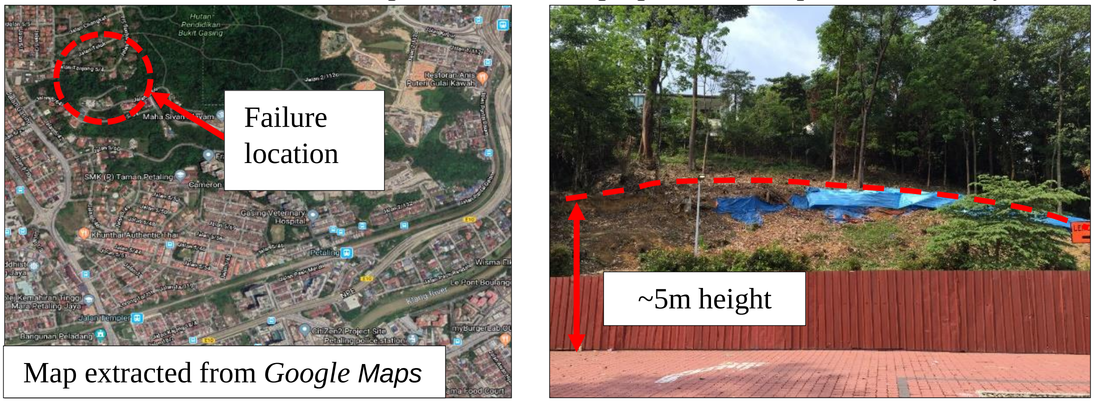
Abstract. Abundance of discarded scrap tyre in Malaysia demand diverse recycling products, in order to reduce its environmental pollutions and simultaneously the negative aftermaths to society and future generation. Hence, this paper is established to investigate the potential of tyre derived geo-material as rock fill alternative in conventional gabion type retaining wall, replacing a portion of the non-renewable rock fill. 4-tier scrap tyre gabion wall (STG wall) in terraced position with various scrap tyre ratio from total gabion rock fills volume are modelled to retain a 5.0m height of existing failed slope. The model are analysed by finite element method in Slope/W 2007 software (Morgenstern-Price analysis method) to assess overall stability of the gabion wall and factor safety (FOS) of the treated slope. From this study, higher FOS is acquired when STG wall incorporated into the failed slope compared to using conventional gabion wall.

1. Introduction

The debris volume at Malaysia landfills consistently increasing year by year consistent with rapid development and population growth. Waste disposal sourcing from construction, clinical (bio-medical), electronics, household, hazardous waste and scrap tyre are mostly end up in landfill [1]. It is found that the quantity of scrap tyre to be recycle is insignificant compared to the generation of scrap tyre [2]. At Port Klang**,** over hundreds of container cargos fill with scrap tyre have been shipped and left abandoned there at Northport and Westport [3]. Local authority mentioned that scrap tyre often mixed with other domestic waste in landfills, especially motorcycles tyre. The unusable tyre in open space attract disease-carrying pests, also has high possibility to pollute soil and groundwater. Imprudent practice of scrap tyre dumping has caused Sabah City Hall to conduct regular fogging activity to prevent the state landfills transform into mosquito habitat [4]. Improper way to decompose it may cause harm to human health and environment. Hence, ways are proposed to increase the recycling rate of scrap tyre while eliminating the hazardous effect. Recent studies proposed the application of scrap tyre as part of geotechnical solution. [5] has studied the compatibility of approximate 5% rubber crumb mixture and polypropylene short fibres towards concrete pavement. Scrap tyre mixed sand are also show potential as lightweight backfill material, replacing a portion of sand material, due to its mechanical properties [6–9]. Meanwhile, this paper focus on providing perspective into application of rock fill shredded scrap tyre mixture in gabion wall. The objectives of the study include assessment of the gabion wall made of rock fill and shredded scrap tyre effectiveness to rehabilitate slope failure also to study the effectiveness of percentage rockfill:tyre mixture ratio in protecting the failed slope.

2. Method

The studied slope data used in this paper are based on actual approximate 5.0m height slope failure event occurred in May 2016 nearby Hutan Pendidikan Bukit Gasing, Petaling Jaya, Selangor as shown in figure 1. The details of the failed slope and its subsoil properties are implied in this study.



(a) (b)

Figure 1. Slope failure at Bukit Gasing, Petaling Jaya, Selangor.

Two slope model are developed and assessed numerically in this paper, a 5.0m height of existing slope without any treatment and the slope model retained with a 4.0m height gabion wall. Engineering software, Geostudio Slope/W 2007 are utilised throughout the analysis, applying Morgenstern-Price type to analyse the slip circle of the slope and provide the global and local Factor of Safety (FOS).

2.1. Slope modelling details

Figure 2 shows slope model without any treatment. Meanwhile, figure 3 display slope model details retained with gabion wall in terraced position. Dimension used throughout the analysis are as per indicated. Considering the critical situation of continuous prolonged rainfall, full level of groundwater is opted in the slope models.

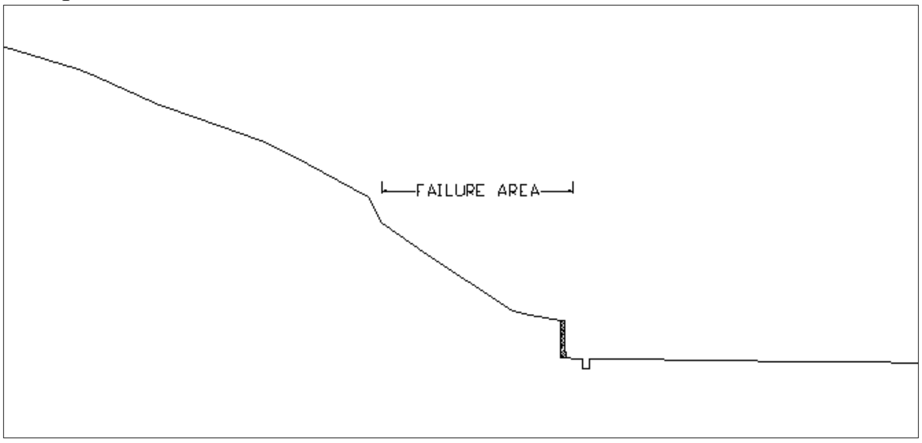


Figure 2. Existing slope model cross-section (without treatment).

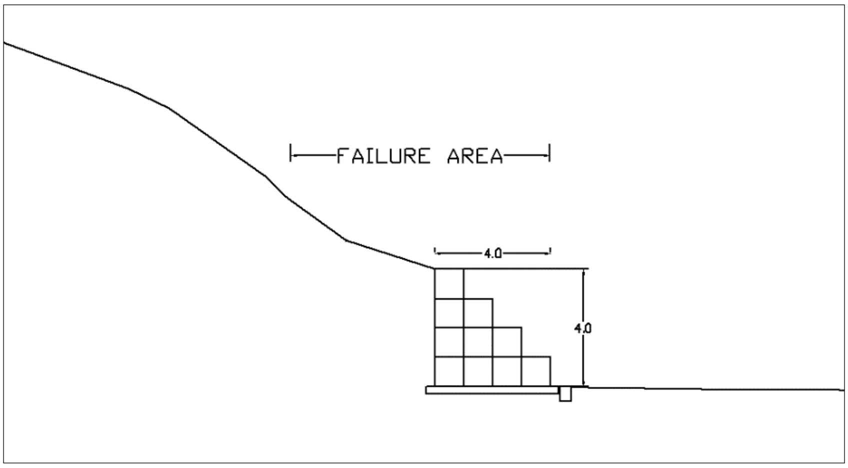


Figure 3. Treated slope model cross-section (with gabion wall).

2.2. Material size

The individual rock fill dimension ranging from 20mm greater than wire mesh opening and maximum dimension of 250mm [10]. According to [10], the wire mesh netting cage shall have minimum 2.70mm diameter with maximum mesh size of 100mm x 120mm, sufficiently coated with polyvinyl chloride (PVC) with minimum thickness of 0.55mm. No consideration is made for the wire mesh strength in analysis as per stated in BS 8002:1994. In analysis, tyre shreds of typical size ranging from 76mm to 305mm are utilised to replace a portion of rock fill volume inside the 1.0m x 1.0m x 1.0m standard size of wire mesh netting cage. Dimension of scrap tyre is assumed to have similar particle size distribution and the STG are assumed to be homogenous in the STG cage.

2.3. Material parameters

Available soil investigation (S.I) report are referred to determine the soil type and parameters. Table 1 summarize the Sandy SILT soil type parameter details.

Table 1. Soil parameters.

Soil layer	Unit weight, γ (kN/m^3)	Cohesion, c (kN/m^2)	Internal friction angle, θ (^{o})	Legend
SPT <20	18	1	29	
SPT 20-50	18	2	30	
SPT 50	19	4	32	

Mechanical properties of the rockfill shredded scrap tyre (STG) mixture used in this study are based on laboratoty test conducted. Unit weight value, γ of STG mixture are determined via Proctor Test while cohesion, c and internal friction angle, θ are obtained from Direct Shear Test. Granulated scrap tyre are purchased from a recycle tyre retread factory in Kuantan, Pahang for the laboratory tests. table 2 summarize the shredded scrap tyre parameters based on laboratory results.

Table 2. Soil parameters.

Model scrap tyre:rockfill mixture	Unit weight, γ (kN/m^3)	Cohesion, c (kN/m^2)	Internal friction angle, θ (^{o})
STG Wall of 0:100 ratio	16.48	1	30
STG Wall of 20:80 ratio	16.68	4	29

2.4. Rockfill shredded tyre mixture

A total of three (3) number of slope model are modelled and analysed in this paper. Table 3 lists the series of slope analysis with different mixture ratio.

Table 3. Soil parameters.

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3. Results and discussion

3.1. Slope stability analysis results

The acceptability of a slope's stability is based on adequate Factor of Safety (FOS) against slope failure. As per Guideline for Slope Design, by Public Works Department Malaysia (see Figure 4), slope is considered stable if the Factor of Safety (FOS) is ≥ 1.5.

	DESIGN COMPONENT	MODE OF FAILURE	MINIMUM FACTOR OF SAFETY	MAXIMUM PERMISSIBLE MOVEMENTS		
				VERTICAL	LATERAL	DIFFERENTIAL
1.	Unreinforced Slopes	1.1 Local & Global Stability (cut & fill slopes) 1.2 Bearing (fill)	1.3 2.0	Analysis should be according to GEOTECHNICAL MANUAL FOR SLOPES (1984), GEO Hong Kong		
2.	Reinforced or Treated Slopes (not on soft ground)	2.1 Local & Global Stability (cut & fill slopes) 2.2 Bearing (fill)	1.5 1.5			
3.	Permanent Anchors	3.1 Tensile Resistance 3.2 Resistance at Soil Grout Interface 3.3 Creep/Corrosion	2.0 3.0	Geo Spec 1 (1989), GEO Hong Kong BS 8081		
4.	Rigid Retaining Structures	4.1 Overturning 4.2 Sliding 4.3 Overall Stability 4.4 Bearing	2.0 1.5 1.5 2.0	15mm along face of wall Geoguide 1 (1983), GEO Hong Kong	15mm along face of wall	1 : 150 along face of wall
5.	Reinforced Fill Walls/Structures	External Stability Internal Stability	BS 8006	± 5mm per metre height	± 15mm from reference alignment	1 : 100 along face of wall
6.	Individual Foundation Piles (mainly under axial loads)	6.1 Shaft Resistance 6.2 Base Resistance	2.0 2.0	12mm along axis of pile at pile head at design load. 38mm or 10% pile size at pile head at twice design load. BS 8004		
7.	Individual Foundation Loads (mainly under lateral & bending loads perpendicular to axis of pile)	Ultimate Lateral Resistance	2.5	12mm along axis of pile at pile head at design load. BS 8004	12mm perpendicular to axis of pile at design load	
8.	Pile Group	Block Bearing Capacity	2.0	12mm at Working Load BS 8004		
9.	Piles as Retaining Structures	As for 4, 6 & 7 above	As for individual foundation piles	As 4 above for rigid retaining structures BS 8004		
10.	Embankment on Soft Ground	10.1 Bearing (short term) 10.2 Local & Global Slope Stability (long term)	1.4 1.2	7 years post construction settlement : (i) within 10m from bridge approach < 100mm (ii) road < 250mm		

Figure 4. Geotechnical Design Criteria for Slopes Design (Jabatan Kerja Raya Malaysia, 2010).

From the back analysis carried out in Geostudio Slope/W 2007 software, it is proven that the slope is failed with FOS 0.956≤1.5 (refer figure 5). Hence, 4.0m height of gabion wall is modelled and analysed. The results shown that the FOS value has slightly increased by 0.2 % applying 20% volume of scrap tyre derived geomaterial, comparing with conventional type of gabion wall. Table 4 summarize the analysis results.

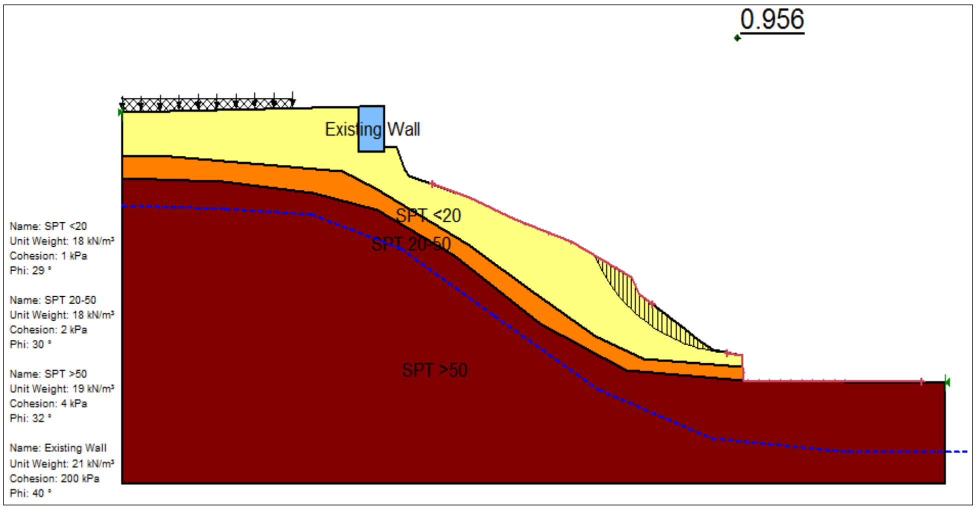

Figure 5. Existing failed slope.

Table 4. Series of slope models (Variance in scrap tyre:rockfill mixture ratio).

Model ID	Factor of Safety
1	0.956 ≤1.5 (Inadequate)
2	1.502 ≥1.5 (Satisfactory)
3	1.505 ≥1.5 (Satisfactory)

Meanwhile, the critical slip circle of slope is also observed. Figure 6 and figure 7 illustrate the output analysis from Geostudio Slope/W 2007. It can be seen that STG wall possess shallower slip circle compared to conventional gabion wall.

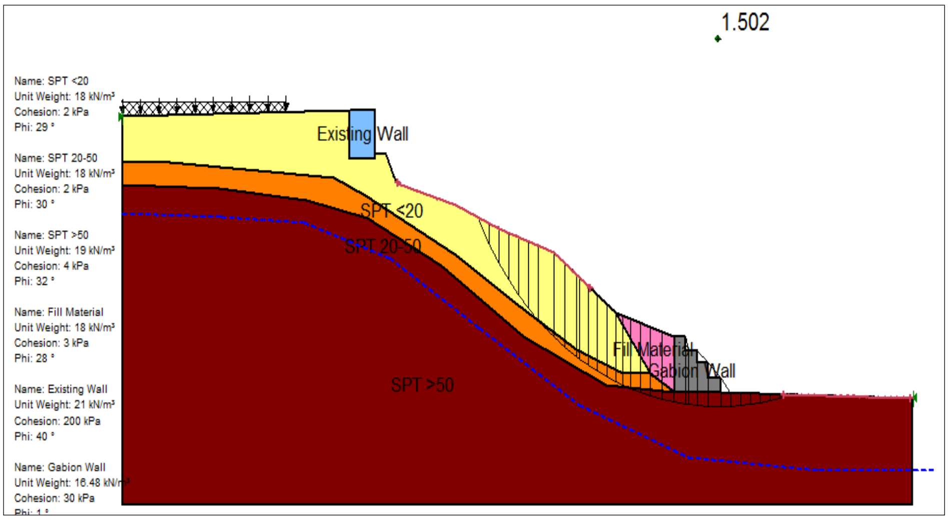

Figure 6. Treated slope of 100:0 rockfill:scrap tyre mixture gabion wall.

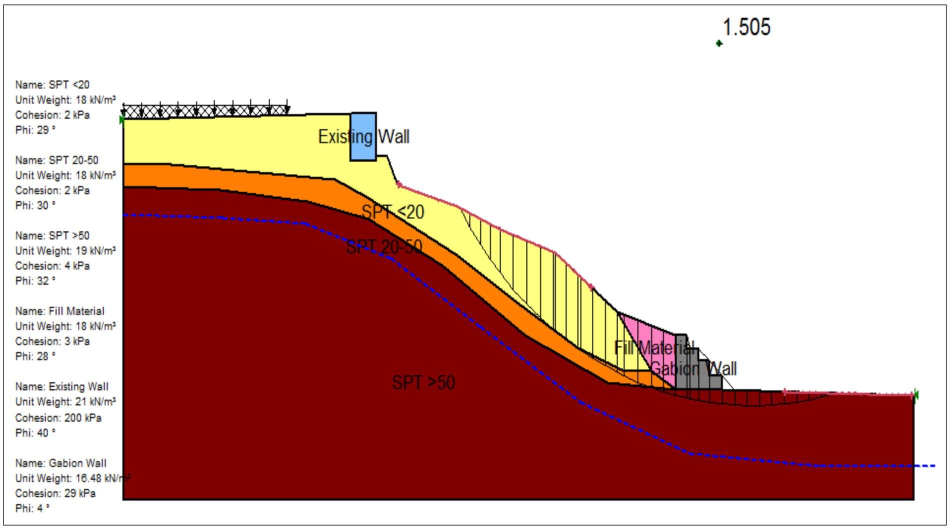

Figure 7. Treated slope of 80:20 rockfill:scrap tyre mixture gabion wall.

4. Conclusion

Numerical modelling and analysis of rockfill shredded scrap tyre mixture gabion type of retaining wall has been carried out. Slip circle and slope Factor of Safety (FOS) are studied and assessed, comparing the results with conventional gabion wall. From this study, STG wall resulted in higher FOS and caused shallower critical slip circle. Overall, scrap tyre derived geomaterial has potential as substitute material to replace a portion of non-renewable rockfill in gabion cages. However, further detailed analysis on the STG wall effectiveness shall be conducted, considering other parameters such as variance in soil parameters, scrap tyre:rockfill mixture ratio and retained heights. Small scale of laboratory experiments is also recommended to be conducted in order to verify the numerical analysis results.

5. References

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Acknowledgments

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