Indonesian Geotechnical Journal, December 2022, Vol 1 (3). Page 19 - 28
DOI: https://doi.org/10.56144/igj.v1i3.32
E-ISSN:2829-7520
https://indonesian-geotechnical-journal.org/index.php/IGJ/issue/archive

Sustainable Retaining Structure Incorporating Recycled Concrete Aggregate

Nurly Gofar[1,*], Alfrendo Satyanaga[2]
[1]Department of Civil Engineering, Post Graduate Program, Universitas Bina Darma, Palembang, Indonesia, 30111; nurly_gofar@binadarma.ac.id
[2]Department of Civil and Environmental Engineering, School of Engineering and Digital Sciences, Nazarbayev University, Nur-Sultan, Kazakhstan, 010000; alfrendo.satyanaga@nu.edu.kz
*Correspondence: nurly_gofar@binadarma.ac.id

SUBMITTED 11 December 2022 **REVISED** 15 December 2022 **ACCEPTED** 16 December 2022

ABSTRACT Recycled concrete aggregate can be produced from construction and demolition waste materials. Recycled concrete aggregate has been used in the construction industry as an alternative for coarse aggregate component in concrete or as backfilling material in retaining structure. This paper presents the results of study on the use of the recycled concrete aggregate in the design of a newly developed sustainable retaining wall i.e., Geobarrier system (GBS). The GBS system was developed based on capillary barrier to limit water infiltration into the backfill soil while vegetative cover is used as provisions of the sustainable construction concept. Two types of concrete aggregate are used as components of capillary barrier i.e., fine and coarse aggregate. Laboratory test result shows the recycled concrete has similar mechanical and hydraulic properties as the natural aggregate; thus, can be used as alternative material. Stability and deformation analyses were carried out for 4 m high wall with 70° inclination. Results indicate that the retaining wall meet the requirement of Eurocode 7 in terms of Factor of safety. Deformation analysis shows that the maximum deformation was only 4.5 mm at the bottom of the GBS wall.

KEYWORDS sustainable construction; recycled concrete aggregate; vegetative cover, retaining structure; Geobarrier system

1 INTRODUCTION

The focus of infrastructure development in Indonesia has increased the demand for utilization of high and steep slopes with gradient greater than 70 degrees. Therefore, the need for retaining structure to stabilize the slope has increased. Conventional retaining structure may not be desirable due to high initial cost, and they are also not environmentally friendly. Furthermore, passive resistance of retaining wall requires large movement to be mobilized (Mei et al, 2009). To reduce wall movement, reinforcement such as soil nailing and/or ground anchor can be added. Other alternatives for retaining structures include the use of gabions, geotextiles and geogrids, wire meshes and shotcrete.

Another method of slope stabilization is the application of bioengineering and soil cover system. In bioengineering method, vegetation is used to help stabilize the slope indirectly through the root system and its effects on the soil moisture regime (Punetha, et.al., 2018). Covering a slope with grass reduces the amount of water which can infiltrate into the soil. Surface drainage can also be used to regulate the amount of water that can infiltrate into the soil. However, the drainage system requires maintenance and repair which can often be difficult to perform and expensive.

A relatively new soil cover system is the capillary barrier system which is a two-layer system of distinct hydraulic properties that is used to prevent water infiltration into the soil below the capillary barrier system by utilizing unsaturated soil mechanics principles (Stormont, 1996). Previous research works have indicated the effectiveness of the capillary barrier system as a soil cover in reducing rainfall infiltration (Rahardjo et al., 2016; Yunusa et al., 2015). In the original design, the capillary barrier system uses fine-grained layer overlain by coarse-grained layer, in which the course-grained layer is derived from natural aggregate or gravel.

Recycled concrete aggregate (RCA), can be easily obtained from construction and demolition waste materials. RCA has been used in the construction industry as an alternative for coarse aggregate component of super-structural concrete, rigid pavements in road construction, road curbing, as well as sewage systems (Rahardjo et al., 2016; Rahardjo et al., 2018a,b). The mechanical characteristics of the concrete waste, such as compressive strength, have been cautiously considered when selecting recycled aggregates. This is due to the fact that compressive strength is directly associated to the frictional behavior of the entire combination of concrete aggregates, which is the main focus in this study. Coarse-RCAs and fine-RCAs were used for as components of capillary barrier system.

GBS is a sustainable retaining structure incorporating the capillary barrier system and vegetative cover (Figure 1). According to Rahardjo et al. (2019b), the GBS consists of three integrated components i.e.: the Retaining Structure System, the Capillary Barrier System, and the Green Cover. The key factor of the slope instability is related to the reduction of soil suction and unsaturated shear strength due to rainwater infiltration. The capillary barrier system in the GBS effectively incumber the rainfall infiltration into the residual soil behind the retaining structure, thus preserving the compacted residual soil's negative pore-water pressure and shear strength (Rahardjo et al., 2018a, 2019a, 2019b). The same research group further evaluates the use of alternative material in the construction of sustainable retaining structures (Rahardjo et al., 2017; Rahardjo et al., 2019a; Satyanaga et al., 2019), which led to the use of coarse-RCAs and fine-RCAs in the development of Geobarrier System (GBS).

The appearance of GBS is enhanced by including suitable vegetation (deep rooted grass, shrubs) as green cover. Combination of green cover and capillary barrier system reduces the coefficient runoff (avoiding flood) and prevent erosion during rainfall since rainwater is directed properly into main drainage via drainage layer (fine-grained layer) of GBS (Rahardjo et al., 2018c; Rahardjo et al, 2019a).

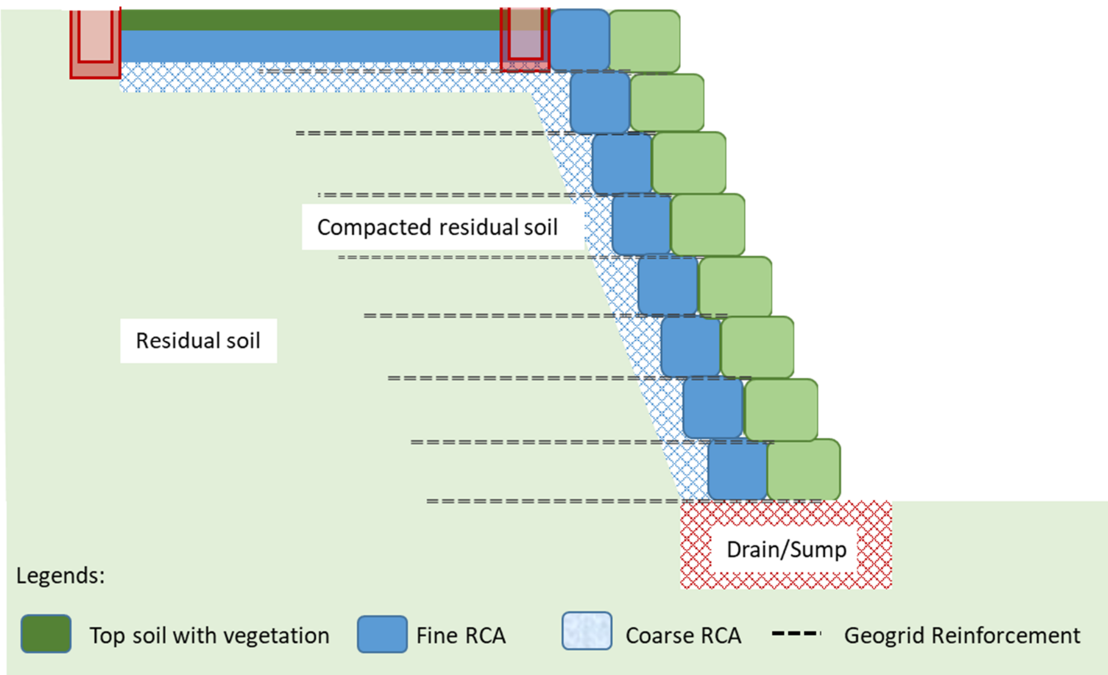


Figure 1. Schematic diagram of the Geobarrier System.

This paper focuses on presenting the performance of the GBS, a reliable and sustainable stabilization system, as the mitigation strategy for slope failure based on a pilot study of a 4 m high wall with 70^o inclination. The originality of this study is the utilization of RCA as alternative material for natural aggregate in the capillary barrier system, and the combination of capillary barrier system with vegetative cover which has not been investigated previously.

2 METHODS

The methodology adopted in this study is the combination of laboratory experiment and numerical analysis. The laboratory experiment focuses on the properties of recycled concrete aggregate to be used as the components of the capillary barrier. The stability analysis was done analytically following Eurocode 7. Numerical analysis focuses on the deformation of the whole GBS system.

2.1 Laboratory Test

The design and implementation of GBS is essential towards the stability of sustainable retaining structures. To guarantee that the RCA fits the requirements as an alternative filler material for the natural aggregate, laboratory tests were conducted to characterize the properties of recycled concrete. The recycled concrete aggregates used in this study are depicted in Figure 2.

Figure 2. Recycled Concrete Aggregate (a) Fine RCA (b) Coarse RCA.

Index properties and engineering properties under saturated and unsaturated conditions were all tested in laboratory for the determination of characteristics of the RCA samples. All of the laboratory testing were conducted in accordance with ASTM standards, i.e. ASTM D7263-09 (density); ASTM D854-02 (specific gravity); ASTM D422-63 (particle size); ASTM D2216-10 (water content); ASTM D4318-00 (Liquid Limit); ASTM D2434-06 (saturated permeability by constant head) and ASTMD2487-00 (soil classification).

Wet and dry sieve analysis were carried out to determine the soil's grain size distribution. Wet sieving was used for fine-grained components (fine-RCA), while dry sieving method (ASTM D6913-04) was used for coarser-grained components (coarse-RCA).

The stability of the GBS's is heavily influenced by the shear strength of all of its components including the compacted soil, fine and coarse RCAs, planting soil and the gravel sumps (see Figure 1). The saturated consolidated undrained (CU) triaxial tests with pore-water pressure measurements (ASTM D4767-11) were used to define the shear strength parameters. The tests were carried out using a constant strain rate of 0.05 mm/min.

Geosynthetics are used to encase the components of a GBS system i.e., the fine RCA and the top soil. In this particular instance, woven monofilament fiber geotextile was used to create a stable wrapping of the filling material with an ideal balance between transmissivity for water flow and soil retention. The diameter of the opening should be smaller than 600 microns. The characteristics of the Geobag which is used in this study were similar with the specifications provided by Rahardjo et al. (2019b).

The soil-water characteristic curve (SWCC) is a common approach for analyzing the correlation between matric suction and water content of unsaturated soil. SWCC could be used to predict the mechanical and hydraulic characteristics of unsaturated materials such as soil and RCA. A Tempe cell with a ceramic disk (1 bar capacity) was used in this study to generate up to 100 kPa matric suctions (Figure 3). The SWCC test was carried out in accordance with ASTM 6836-02. Before the tests, the ceramic disk was prepped in a vacuum environment (for example, vacuum box) to remove air bubbles in the ceramic disk. Upon the completion of the saturation phase, the soil sample was put in a Tempe cell. The ceramic disk was then placed beneath the RCAs sample to separate the pore-air and pore-water pressure connections. The bottom of the RCAs sample must have good contact with ceramic disc to ensure continuous water flow during the tests.

After preparing the RCA sample in the vacuum condition, matric suction was applied in the Tempe cell. Matric suction is described as the pressure exerted around the test sample in order to balance the water content in the RCA specimen's total volume. The axis-translation method by Marinho et al. (2008) was used in this circumstance by assigning matric suction to the RCA samples.

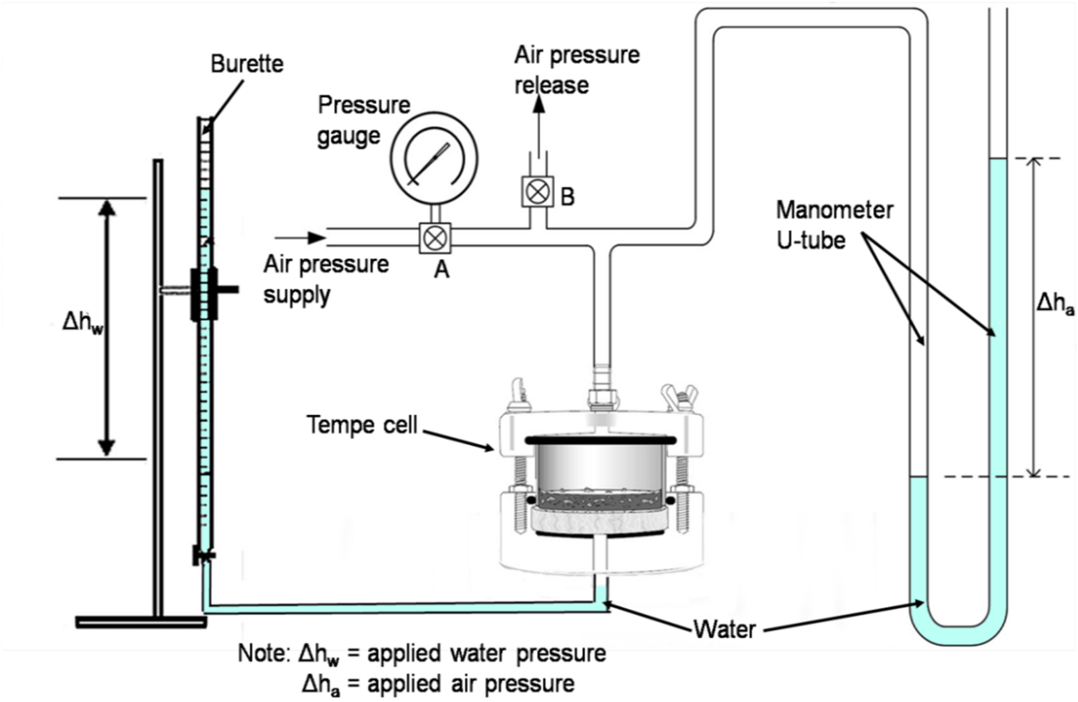


Figure 3. Layout of SWCC testing using Tempe Cell.

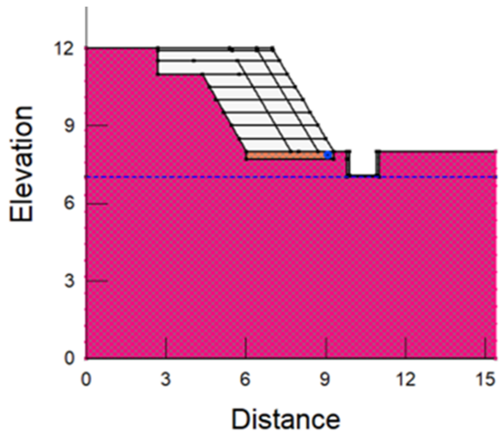
Saturated permeability experiments were performed in a triaxial cell with two back pressure system of measurement. The constant head permeability technique was used for both fine- and coarse- RCA. The triaxial cell with two backpressure mechanisms was prescribed for the constant-head saturated permeability experiment.

2.2 Deformation Analysis

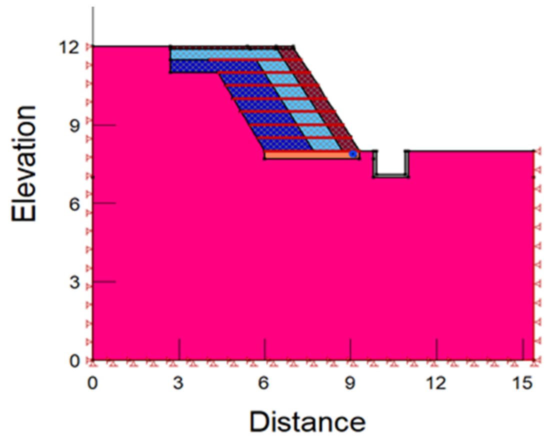
The pilot project analyzed in this study was 4-m high GBS wall with 70° inclination and 8 km long. The GBS is evaluated in this study to estimate the maximum deformation that might occur due to overburden pressure and external load as well as pore water pressure distribution when the wall is subjected to rainfall infiltration. The deformation analysis was performed using SIGMA/W integrated in GEO-SLOPE International (2012). The soil data derived from laboratory tests were used in the analysis.

The accuracy of the numerical analysis results depends on the placement of boundary conditions. The distance between the top of slope and the bottom boundary is purposefully set to be three times the slope height. This is required to eliminate the boundary effects. For the left and right boundaries, soil is allowed to move in vertical direction but fixed in horizontal direction. The bottom boundary is fixed in both vertical and horizontal direction. The reinforced soil was taken into account in the calculation in order to create an accurate stressing condition of the slope. As shown in Figure 4, the position of the groundwater level was speculated to be 1 meter below the base of the GBS slope. The initial hydraulic condition of the slope was chosen as a hydrostatic pore-water pressure condition based on the location of the groundwater level.

The numerical analysis was carried out for the GBS considering the construction phases similar to that presented in Rahardjo et al., (2019b). The construction phase of the overall system started with a field geostatic condition and the position of the GeoBags to create initial condition. Figure 4a shows the slope condition before the placement of GBS. Overall, there were 14 construction phases of analysis between the initial and the final condition. The GBS at the completion of construction is depicted in Figure 4b.



(a)



(b)

Figure 4. Numerical analyses (a) before placement of GBS and (b) upon completion of GBS construction (right).

2.3 Stability analysis

Stability analysis is required before initiating any construction activities including the GBS system as the sustainable retaining structures. The following criteria must be fulfilled in order to verify the safety of a sustainable retaining structure (Namita 2018): First, the sustainable retaining structures must be able to withstand the force from all directions during implementation, especially lateral pressure from the soil behind the retaining structure. Second, the total mass of structures must not cause bearing capacity failure of foundation soil. Third, the design of the sustainable retaining wall should ensure no built-up pore-water pressure occurred behind the wall and there should be sufficient drainage capacity at the toe of the wall. Furthermore, the retaining structure design must be safe against (a) internal stability i.e., geotextile tensile and pull-out strength, and (b) external stability i.e., sliding, overturning, and bearing capacity. In this study, to stability evaluation was performed following Eurocode 7 regulations, and the results is presented in terms of Factor of Safety (FoS).

3 RESULTS AND DISCUSSION

The properties of RCA and other components of the GBS wall are shown in Table 1. From, this table, the properties of coarse RCA are similar to those of Gravel which is used herein as material for sump.

Table 1. Shear strength of GBS component materials

Soil Type	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)
Compacted Soil	18.2	2	28
Coarse RCA	17.0	0	42
Top soil	18.5	5	33
Gravel	17.0	0	42
Fine RCA	18.0	0	36

Figure 5 and Figure 6 portrayed the fitting curve of SWCC based on laboratory tests and the calculated unsaturated permeability function based on the saturated permeability and SWCC using Fredlund and Xing (1994) equation. The air entry value (AEV) of the fine RCA is 25 kPa while the AEV of coarse RCA is 5 kPa. Thus, there is a ratio of 5 between the AEV of fine and coarse RCA which indicate that the combination is effective as capillary barrier (Rahardjo et al, 2007). The residual suction of fine RCA is 100 kPa while that of coarse RCA is 50 kPa. The saturated permeability of the fine RCA is 4×10^{-5} m/s while the saturated permeability of the coarse RCA is 5×10^{-3} m/s. The water is retained in the fine layer and flow effectively to the drainage below the toe of the wall.

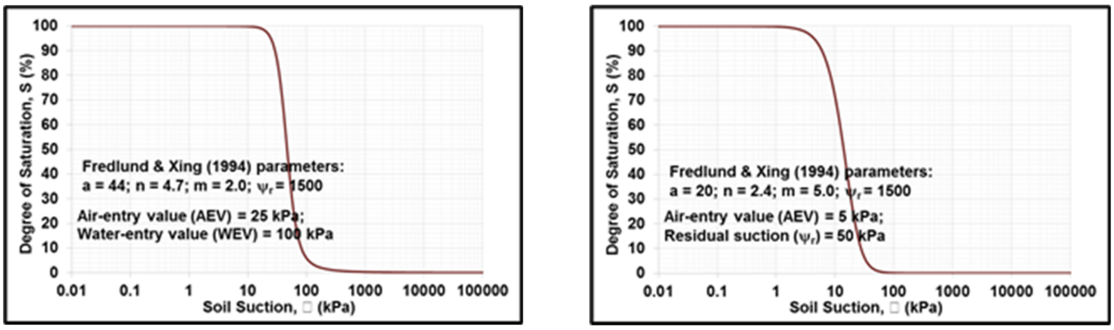


Figure 5. SWCC of fine RCA (left) and coarse RCA (right)

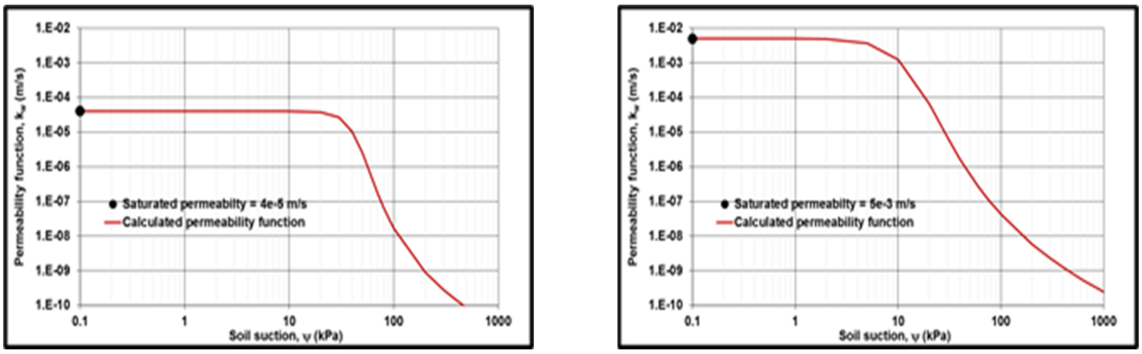


Figure 6. Calculated permeability function of fine RCA (left) and coarse RCA (right)

Figure 7 shows the output of the deformation analysis. The maximum deformation was about 4.5 mm at the bottom of the GBS. This deformation is significantly small in comparison to the overall system. Therefore, the GBS wall was concluded safe to be constructed.

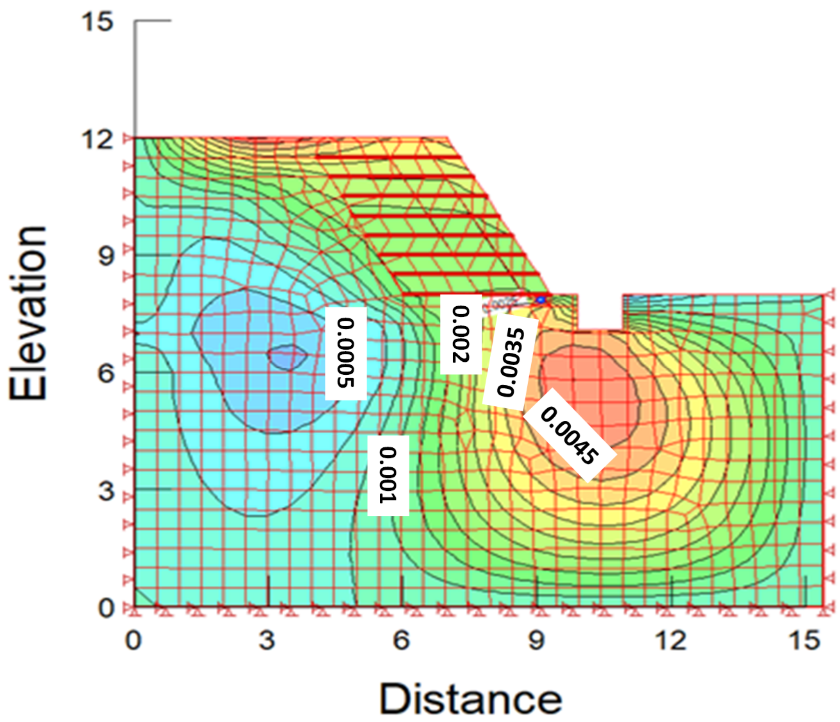


Figure 7 Deformation of GBS system

The FoS obtained from stability analysis are listed in Table 2. The resulting Factor of safety is in accordance with Eurocode 7 for sustainable retaining wall construction; thus, the wall could be constructed.

Table 2. Factors of safety based on Eurocode 7

EUROCODE 7	Name	FOS
EQU	Overturning check	1.73
DA1COMB1	Sliding check	1.66
DA1COMB2		1.41
DA1COMB1	Geotextile check	1.74
DA1COMB2		1.95
DA1COMB1	Bearing Capacity check	3.77
DA1COMB2		2.41

4 CONCLUSIONS

The laboratory test results showed that the mechanical and hydraulic properties of recycled concrete aggregate (RCA) is similar to the natural aggregates, implying that RCAs could be used as substitution of natural aggregates. Stability analysis of the GBS wall studied herein confirmed that the factor of safety met the requirement of Eurocode 7 for all modes of failure. Deformation analysis shows that the maximum deformation of the wall was only 4.5 mm at the bottom of the GBS. Thus, the GBS can be built using RCA as filling material with inclination up to 70°.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the authors.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Dr. Ging Meng for his support and guidance with gathering and analysis of the data for this research.

REFERENCES

Eguchi, K., Teranishi, K., Nakagome, A., Kishimoto, H., Shinozaki, K., Narikawa, M., 2007. Application of recycled coarse aggregate by mixture to concrete construction, *Construction and Building Materials*, 21(7), pp. 1542-1551. https://doi.org/10.1016/j.conbuildmat.2005.12.023

Fredlund, D.G., and Xing, A., 1994. Equations for the soil-water characteristic curve. *Canadian geotechnical journal*, 31(4), pp. 521-532. https://doi.org/10.1139/t94-06

Ip., S.C.Y., Satyanaga, A. and Rahardjo, H., 2021. Spatial variation of shear strength properties incorporating auxiliary variables. *Catena*, 200, pp. 1-12. https://doi.org/10.1016/j.catena.2021.105196

Marinho, F.A.M., Take, W.A., and Tarantino, A., 2008. Measurement of Matric Suction Using Tensiometric and Axis Translation Techniques. In *Laboratory and field testing of unsaturated soil*, pp. 3-19. https://doi.org/10.1007/978-1-4020-8819-3_2

Mei, G.M., Chen O., and Song, L., 2009 Model for Predicting Displacement-dependent Lateral Earth Pressure. *Canadian Geotechnical Journal*, 46(8). https://doi.org/10.1139/T09-040

Namita, 2018. *Retaining Wall | Types of Retaining Walls | Design Considerations*. [Online] Available at: https://civildigital.com/retaining-wall-types-retaining-walls-design-considerations

Punetha, P., Samanta, M., Sarkar, S., (2019). Bioengineering as an Effective and Eco-friendly Soil Slope Stabilization Method: A Review. In: Pradhan, S., Vishal, V., Singh, T. (eds) *Landslides: Theory, Practice and Modelling. Advances in Natural and Technological Hazards Research*, vol 50. Springer, Cham. https://doi.org/10.1007/978-3-319-77377-3_10

Rahardjo H., Krisdani, H., Leong E.C, 2007. Application of Unsaturated Soil Mechanics to Capillary Barrier System for Slope Stabilization. *Proceedings of 3rd Asian Conference on Unsaturated Soils*, Nanjing, China, pp. 127–137.

Rahardjo, H., Satyanaga, A. & Leong, E.C., 2016a. Effects of rainfall characteristics on the stability of tropical residual soil slope. *Proceedings of E-UNSAT 2016, E3S Web of conferences*, 9, pp. 1-6, https://doi.org/10.1051/e3sconf/20160915004

Rahardjo, H., Satyanaga, A., Harnas, F.R., and Leong, E.C., 2016b. Use of Dual Capillary Barrier as Cover System for a Sanitary Landfill in Singapore. *Indian Geotechnical Journal*, 46(3), pp. 228-238. https://doi.org/10.1007/s40098-015-0173-3

Rahardjo, H, Prasad, Satyanaga, A., Mohammad, H., Leong, E.C., Wang, C.L., and Wong, L.H., 2017. 1-D Infiltration Behavior of Two-layered Recycled Concrete Aggregates using Hydrophobic Materials in a Column Apparatus. *Journal of Materials in Civil Engineering*, ASCE, 29(8), pp. 1-11. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001876

Rahardjo, H., Gofar, N. and Satyanaga, A., 2018a. Effect of Concrete Waste Particles on Infiltration Characteristics of Soil. *Environmental Earth Science*, 77(9), pp. 1-12. https://doi.org/10.1007/s12665-018-7530-3

Rahardjo, H., Gofar, N., Harnas, F. and Satyanaga, A., 2018b. Effect of Geobags on Water Flow through Capillary Barrier System. *Geotechnical Engineering Journal of the SEAGS & AGSSEA*, 49(4), pp. 73-78.

Rahardjo, H., Kim, Y., Gofar, N., Leong, E.C., 2018c. Field Instrumentations and Monitoring of GeoBarrier System for steep slope protection. *Transportation Geotechnics*, 16, pp. 29-42. https://doi.org/10.1016/j.trgeo.2018.06.006

Rahardjo, H., Gofar, N., Satyanaga, A., Leong, E. C., Wang, C. L., Wong, J.L.H., 2019a. Effect of rainfall Infiltration on Deformation of GeoBarrier Wall. *Geotechnical and Geological Engineering*, 37(3), pp. 1383–1399. https://doi.org/10.1007/s10706-018-0693-6

Rahardjo, H., Satyanaga, A., Gofar, N., Leong, E.C., Jernice, K.H., Wang C. L., Wong, J.L.H., 2019b. GeoBarrier System for Protection Against Rainfall-induced Slope Failure. *ISSMGE International Journal of Geoengineering Case Histories*, 5(1), pp. 26-42.

Satyanaga, A. and Rahardjo, H., 2020. Role of Unsaturated Soil Properties in the Development of Slope Susceptibility Map. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering*, 175(3), pp. 276-288. https://doi.org/10.1680/jgeen.20.00085

Satyanaga, A., Rahardjo, H. and Hua, C.J., 2019. Numerical Simulation of Capillary Barrier System under Rainfall Infiltration. *ISSMGE International Journal of Geoengineering Case Histories*, 5(1), pp. 43-54. http://dx.doi.org/10.4417/IJGCH-05-01-04

Stormont, J.C. and Anderson, C.E., 1999. Capillary barrier effect from underlying coarser soil layer. *Journal of Geotechnical and Geoenvironmental Engineering*, 125(8): pp. 641-648. https://doi.org/10.1061/(ASCE)1090-0241(1999)125:8(641)

Yunusa, G.H. Kassim, A. and Gofar, N., 2015. Effect of Fine-Grained Soil Layer Thickness on the Performance of Modified Capillary Barrier System. *Malaysian Journal of Civil Engineering*, 27. https://doi.org/10.11113/mjce.v27.15942

- This page is left intentionally blank -