Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Sustainability Study on Geosynthetic Reinforced Retaining Wall Construction

Sateesh Pisini[1], Swetha Thammadi[1], Sanjay Shukla[1]

[1]Department of Civil Engineering, Fiji National University, Suva, Fiji.
sateesh.pisini@fnu.ac.fj; swetha.thammadi@fnu.ac.fj;
s.shukla@fnu.ac.fj

Abstract. Geotechnical engineering is the most resource-demanding sub-discipline of civil engineering and considerably impacts the sustainable development of infrastructure. The design and construction of retaining walls play a vital role in geotechnical engineering practices around the world in the development and maintenance of infrastructure. Geosynthetics are an emerging construction material for geotechnical structures (retaining walls, road and railway embankments, unpaved roads, steep slopes, etc.), ground improvement projects, erosion control, drainage and filtration control around geotechnical structures, landfills, etc. This paper presents the evaluation of sustainability for a traditional cantilever retaining wall and a geotextile-reinforced retaining wall using the resource consumption indicator of sustainability matrix. The silty sand base material and dense gravel as backfill material have been considered for this study. The quantitative framework has been established for the suitability of traditional concrete and the geotextile reinforced walls. It was concluded that Geotextile reinforced retaining wall with wrap-around facing is more resource efficient, economical and durable.

Keywords: Retaining wall, Geotextile, Embodied energy

1 Introduction

Geotechnical Engineering being the most resource intensive due to its involvement in the early stages of a project, potentially influences the sustainability of all civil engineering projects. It is generally unnoticed because the energy used is indirect in nature, that is, in the form of materials and natural resources (e.g., land use, steel and concrete) as reported by Misra et. al. [1]. Resources utilized in the process are accounted for by the thermodynamics-based energy accounting methods of exergy, emergy, and embodied energy. Exergy accounting methods are mostly used in procedures involving chemical reactions in industrial manufacturing. Emergy is used as an environmental engineering accounting instrument. Embodied energy is basically 2heat energy. Materials that are low in embodied energy should be used for a sustainable process. Environmental sustainability in geotechnical construction is often equated to resource efficiency parameterized by the embodied energy or embodied CO_2 of the materials used in a project by Chau et al. [2].

In this paper, study is conducted on two retaining walls – conventional reinforced cement concrete cantilever retaining wall and geotextile-reinforced retaining wall. Conventional retaining walls are abundantly seen in the field. Construction of geosynthetic reinforced retaining walls has become a common practice globally in the past few decades. They have been proven to be a cost-effective solution to traditional retaining wall construction as mentioned by Bathrust et. al. [3]. Woven geotextiles and geogrids are commonly used as components of soil reinforcement in geosynthetic-reinforced retaining walls, also known as mechanically stabilized earth (MSE) walls. The geosynthetic layers are included in the backfill at designed vertical spacing. The backfill is compacted at the desired density. Compared to conventional concrete retaining walls, the construction of geotextile-reinforced retaining walls is simple and cost-effective. The performance of a geosynthetic-reinforced wall depends heavily on how the facing components are designed and built. The facing components can be mounted, as the wall is being built or after it is built. Shukla[4] specified that the various kinds of face panels include geosynthetic wraps, pre-cast segmental reinforced concrete panels, segments/modular concrete blocks (MCBs), full-height panels of pre-cast concrete, wire mesh panels and gabion baskets. A wraparound faced retaining wall has been chosen for the purpose of this study. The resource indicator is used for establishing the sustainable option of choice of best retaining wall in terms Exergy, Emergy and Embodied energy.

2 Case study

A retaining wall with silty sand base material and dense gravel backfill material has been considered for this study. The retaining wall design with all details for in-situ base soil, backfill, masonry, concrete, reinforcement and loading details are shown in Tables 1 and 2 as well as Fig. 1 and 2. Alternatively, a geotextile wraparound-faced retaining wall design with the reinforcement length, lap length and spacing of geotextile has been proposed. Exergy, Emergy and Embodied energy techniques of energy accounting are used to model the energy flow process.

Study on several types of retaining walls shows that the supported structures use less embodied energy throughout the models than the cantilever structures and that the material energy occupies the biggest proportion of energy consumption within the design developed by Chau et al. [2]. Although the amount of steel used was much lower than that of concrete, steel was the dominant material energy contributor. They have proposed that the use of recycled steel would reduce the consumption of material energy. It has been reported that the embodied energy consumption can be used as an indicator of environmental impact, although other parameters such as carbon dioxide emissions should also be studied for an extensive assessment. In this research, an attempt to compare the conventional retaining wall with geotextile-reinforced retaining wall in Table 5.

2.1 Design details of Cantilever Retaining Wall

The present case study is a comparison of cantilever retaining wall (CRW) with that of geotextile-reinforced retaining wall with wrap-around facing. The necessary calculations for design of CRW have been made as per the AS 4678-2002 [5]. The geometric details of conventional retaining wall are mentioned in Fig. 1.

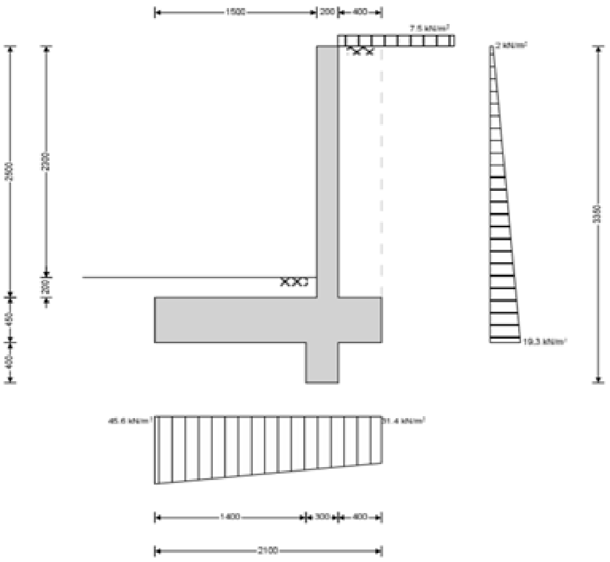

Fig. 1. Conventional cantilever retaining wall

The retained and base soil properties, loading details of CRW are well detailed in Tables 1 and 2. The properties of concrete and reinforcement are mentioned in Fig. 2 based on specifications as per AS 3600-2009 [6] and AS 3700-2011 [7] published by Standards Australia.

Table 1. Retained soil properties.

Soil type	Dense gravel
Soil condition	In situ
Moist density	17.5 kN/m^3
Saturated density	20.8 kN/m^3
Effective internal friction angle	36°
External wall friction angle	18°

Table 2. Base soil properties

Soil type	Stiff clay
Soil conditions	In situ
Soil density	19 kN/m^3
Effective cohesion	30 kN/m^2
Effective internal friction angle	18°
External wall friction angle	9°

External base friction angle	12˚
Ultimate design bearing capacity	150 kN/m²
Loading details	
Live surcharge load	5 kN/m²

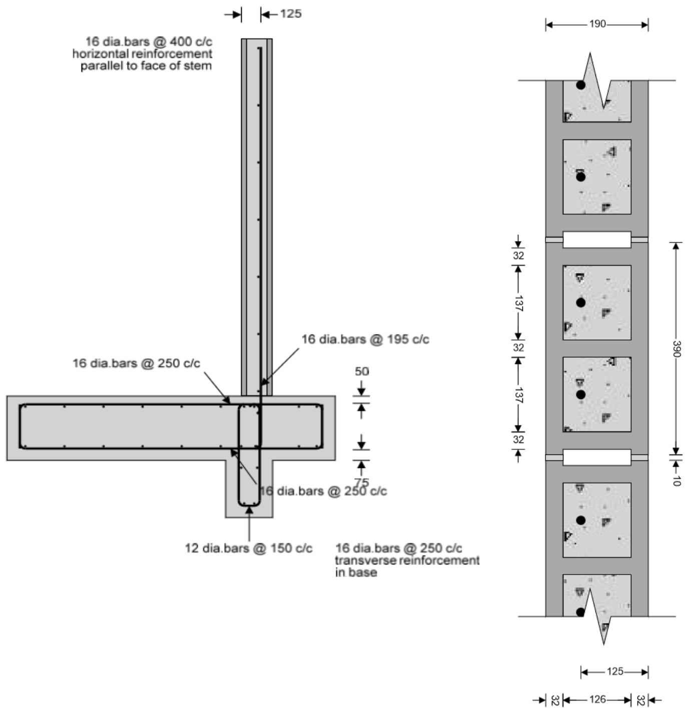

Fig. 2. Cross sectional details of Reinforcement and Masonry

2.2 Design of Geotextile-Reinforced Retaining Wall

The method for design of wraparound-faced geotextile reinforced retaining wall (GRRW) as explained by Shukla [4] has been adapted in the current study with the details on properties of granular material and design parameters of GRRW as in Table 3 along with formulae used for design of GRRW. Fig. 3 represents the schematic sketch of geotextile-reinforced retaining wall with wrap-around facing. On the other hand, Table 4 shows the calculations for properties of geotextile layers for this case study. The design of GRRW has been based on analysis for internal stability, external stability and analysis for the facing system. The actual height of the conventional retaining wall is 2.5 m from the case study.

Table 3. Properties of granular backfill and design parameters of GRRW.

Total unit weight (γ_b)	17.5 kN/m²
Angle of internal friction (ϕ_b')	36°
Effective angle of soil-reinforcement interface (ϕ_i')	$\frac{2}{3}\phi_b'$
Allowable tensile strength (σ_{all})	20 kN/m
Factor of safety against geotextile rupture (F_R)	1.5
Factor of safety against geotextile pullout (F_P)	1.5
Coefficient of active earth pressure (K_a)	0.259
Spacing of Geotextile layers (S_v)	$\frac{\sigma_{all}}{(K_a \gamma_b z) F_R}$
Effective length of Geotextile layer (L_e)	$\frac{S_v K_a F_p}{2\tan(\phi_i')}$
Length of Reinforcement layer (L_r)	$\frac{H-z}{\tan(45+\phi_b'/2)}$
Lap Length (L_l)	$\frac{S_v K_a F_p}{4\tan(\phi_i')}$

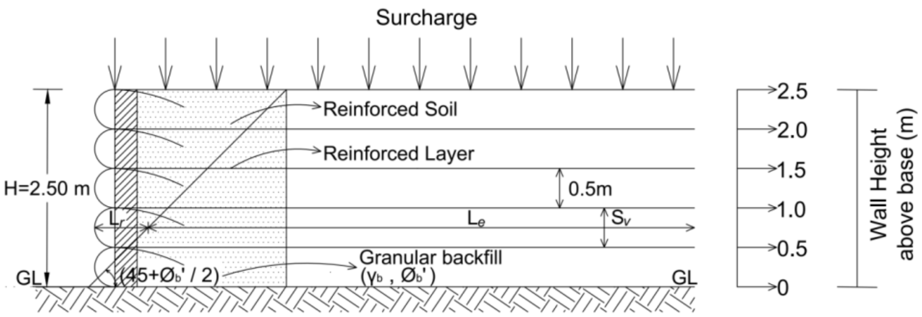

Fig. 3. Schematic sketch of GRRW with wrap-around facing

Table 4. Properties of Geotextile layers for this case study

Layer No.	Depth, z (m)	σ_v (kN/m^2)	σ_h (= $K_a.\sigma_v$) (kN/m^2)	S_v (m)	L_e (m)	L_r (m)	L (= L_e+ L_r) (m)	L_l (m)
1	0.5	8.75	2.275	5.86	2.57	1.02	3.59	1.28
2	1	17.5	4.55	2.93	1.28	0.77	2.05	0.64
3	1.5	26.25	6.825	1.95	0.86	0.51	1.37	0.43
4	2	35	9.1	1.47	0.64	0.26	0.90	0.32
5	2.5	43.75	11.375	1.17	0.51	0.00	0.51	0.26

Further, keeping the field aspects and construction simplicity in view, it is recommended to use the spacing of geotextile layers (S_v) = 0.5 m, length of the geotextile layers (L) = 1 m and lap length (L_l) = 1 m for z ≤ 4m. In general, a minimum reinforcement length of 2.4 m, regardless of the wall height, has been recommended, predominantly due to limitations in size during conventional spreading as well as for compaction equipment. Therefore, in this case, the reinforcement length of 2.5 m has been considered for resource consumption calculation for GRRW.

3 Methodology

The calculations for land use are based on the volume of soil excavated for the construction of retaining wall using parameters mentioned in Fig. 1. Volume of cement and steel have been calculated based on the reinforcement details in Fig. 2.

The Exergy values of unit emergy for cement and steel have been adopted from Brown et.al. [8] and Pulselli et. al. [9] while the values of unit emergy for land is used from the emergy folios of Odum [10]. The embodied energy values per unit mass are adopted from ICE Database version 1.6a [11]. The exergy values of cement and steel used in the calculations are the same as those used by Berthiume et al. [12], and are originally based on the values calculated by Szargut et al. [13]. Table 5 shows the resource indicator calculation for conventional retaining wall and geotextile-reinforced retaining wall with wraparound Face. Also, Fig. 4 illustrates the percentage projection of emergy/embodied energy/Exergy to total resource consumption (emergy + embodied energy + exergy) of CRW and GRRW, respectively.

Table 5. Resource use indicator calculations for CRW and GRRW.

RESOURCE CONSUMPTION CALCULATION FOR CONVENTIONAL RETAINING WALL

Sl No.	Materials	Volume (m3)	Density (Kg/m3)	Mass (Kg)	Emergy		Embodied Energy		Cumulative Exergy	
					Emergy Intensity (×1011) (sej/Kg)	Total Emergy (×1011) (sej)	Embodied Energy Intensity (MJ/Kg)	Total Embodied Energy (MJ)	Unit Exergy (MJ/Kg)	Total Exergy (MJ)
		1	2	3 = 2 * 1	4	5 = 3 * 4	6	7 = 6 * 3	8	9 = 8 * 3
1	Soil	1.785	1784.5	3185.3325	28	89189.31	0.45	1433.3996	0.02	63.70665
2	Cement	355	2400	852000	19.7	16784400	4.6	3919200	5.35	4558200
3	Steel	0.00733	7850	57.5405	41.3	2376.42265	36.4	2094.4742	41	2359.1605
				Total		16875966		3922728		4560623

RESOURCE CONSUMPTION CALCULATION FOR GEOTEXTILE-REINFORCED RETAINING WALL WITH _WRAPAROUND FACE

Sl No.	Materials	Surface Area (m2)	Surface Density (g/m^2)	Mass (kg)	Emergy		Embodied Energy		Cumulative Exergy	
					Emergy Intensity (×1011) (sej/kg)	Total Emergy (×1011) (sej)	Embodied Energy Intensity (MJ/kg)	Total Embodied Energy (MJ)	Unit Exergy (MJ/kg)	Total Exergy (MJ)
1	Soil	1.785	1784.5	3185.3325	28	89189.31	0.45	1433.3996	0.02	63.70665
4	Plastic (PVC)	0.0025	400	0.001	58.5	0.0585	77.2	0.0772	67	0.067
				Total		89190		1433		64

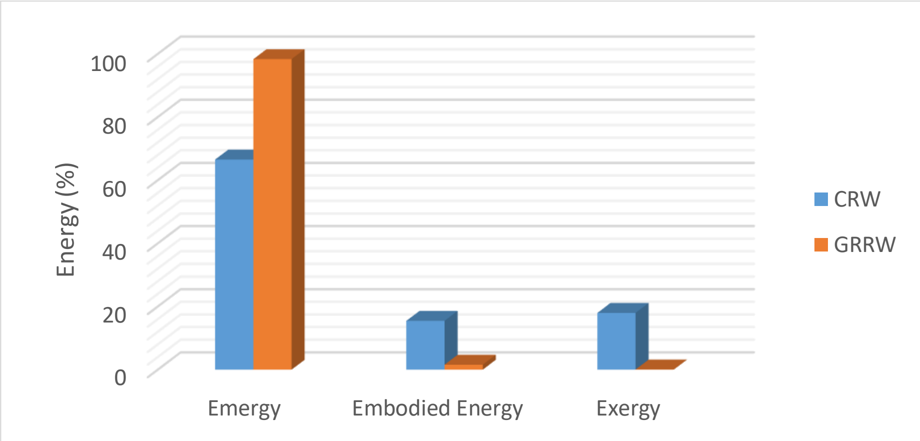

Fig. 4. Resource consumption of Emergy, Embodied Energy and Exergy to total energy consumption for CRW and GRRW.

Although the calculations for exergy and emergy have been done, conventionally embodied energy consumption is used to represent energy use of the materials chosen. The reason being that LCA of buildings and building materials is traditionally done using embodied energy as stated by Chau et al. [2] and Storesund et al [14].

4 Conclusions

Considering the design of the proposed alternatives and results of this research, the conclusions of this research are summarized below:

1. The percentage contribution of emergy is greater in the case of GRRW compared to CRW. However, it is to be noted that emergy, embodied energy and exergy values for GRRW are negligible when compared to that of CRW.
2. The results of the resource consumption calculation show that GRRW is more resource-use efficient compared to CRW.
3. Height of retaining wall considered for this study is 2.5 m whereas, if the height of the wall is more than 4 m, then the compilation of results would allow GRRW to be substantially resource efficient and highly economical as compared to CRW.
4. Calculation of the resource consumption would be effective when comparing similar materials for the best alternative among available options of design and construction of retaining walls.

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