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Greenheart Timber Strip Reinforcement for Reinforced Soil Retaining Walls

Sean A. Surujdas[1] and C.N.V. Satyanarayana Reddy[2]
[1]*Post Graduate Student, Department of Civil Engineering, Andhra University, Visakhapatnam*
[2]*Professor, Department of Civil Engineering, Andhra University, Visakhapatnam*
E Mail: csatyanarayanareddy@yahoo.co.in

ABSTRACT: This article presents the result of investigating the feasibility of using greenheart timber strips as reinforcement for reinforced soil retaining walls in Guyana. The work is intended to assess the cost economics between greenheart timber strips and geogrids as reinforcements. Medium grained river sand is used as fill material in reinforced soil retaining wall designs. The interfacial friction between greenheart timber and fill material is determined by the laboratory pullout test. The designs of reinforced soil retaining wall revealed that Greenheart timber strips of 350mm width and 25mm thickness are sufficient to reinforce retaining walls with backfill of heights 4m and 6m, while greenheart timber strips of 350mm width and 50mm thickness are sufficient to reinforce retaining walls with backfill of heights 8m and 10m. It is observed that as height of retaining wall increases from 2m to 10m, the percentage cost saving of using greenheart timber strips as compared with geogrids, increases from 10% to 24%.

KEYWORDS: Greenheart timber, Pullout test, Interfacial Friction, Cost Economics, Reinforced Soil, Geogrid, Retaining wall.

1. INTRODUCTION

Guyana is a country in Northern South America and is part of the Caribbean South America, bordering the North Atlantic Ocean, between Suriname and Venezuela. About 75% of total land area (16.45 million hectares) is occupied by forest, thus making timber an abundant resource. Greenheart timber (Chlorocardium rodiei) is a tropical hardwood that is world renowned for its strength and durability. It is environment friendly and finds its use for most heavy construction works in Guyana.It is highly resistant to decay, termites, fire and marine organism. Table 1 presents the properties of greenheart timber.

Greenheart timber requires no treatment and is three to four times stronger than pine or fir.This superior timber has been engineered and used in many projects such as pile foundations, fender system, bridges, buildings, lock gates, decking etc. Other common names of greenheart timber include cogwood, demerara greenheart, ispingo moena, sipiri, bebeeru and bibiru.

Table 1 Properties of Greenheart Timber

Property	Value
Flexure strength (N/mm^2)	23.0
Tensile strength (N/mm^2)	13.8
Compressivestrength (N/mm^2)	23.0
Shear strength (N/mm^2)	2.6
Modulus of elasticity (N/mm^2)	24500
Average density (kg/m^3)	1080
Resistance to fungi	Very durable
Resistance to dry wood insect borers	Durable
Resistance to termites	Durable
Treatability	Not permeable
Stability	Moderately stable to poorly stable
Fiber saturation point (%)	40

Source: BS 5268 – part 2

The present construction of retaining walls in Guyana is by greenheart timber pile driving\sheet piling method and reinforced concrete method. Both of these methods are time consuming due to driving operation of timber piles and curing process of concrete. Geosynthetic reinforced soil retaining walls are seldom being considered due to the high importation cost of geosynthetic materials.

The present work investigates the possibility of using greenheart timber strips as reinforcement for the construction of reinforced soil retaining walls in Guyana. The main aim is to determine the dimensions of greenheart strips required to internally stabilize the Reinforced Soil retaining walls for proposed height of backfill and to assess the cost economics between greenheart timber strip and geogrid reinforced soil retaining walls. The interfacial friction between greenheart timber and selected fill material is determined from laboratory pullout test as it better simulates field conditions compared to modified direct shear test.

2. LITERATURE REVIEW

2.1 Review of Timber as Construction Materials

The use of logs or tree trunks of uniform sizes, fixed together to form a mattress for crossing marshy areas, is quite old (Koerner, 2012). Jones (1985) made references to the use of timber elements in the construction of reinforced wharves and soil fills in the older days. Pasley (1822) of the British army made use of alternate horizontal layers of brushwood, wooden planks and canvas in soil backfill. He deduced that such an arrangement, in combination with soil, reduced lateral pressures significantly.

Poorooshasb et al. (1988) presented a case study of stabilization of a residual soil slope in Brazil using bamboo. He presented a design methodology based on which the spacing and length of timber are arrived at to restrict the slope movement. Datye (1988) presented the use of timber and bamboo as reinforcement for Indian soil conditions along with their cost economics.

3. EXPERIMENTAL WORK

3. 1 Materials

3.1.1 Greenheart Timber

Greenheart timber was imported from Guyana. The strips were prepared by cutting to dimension 120mm length x 40mm width x 5mm thickness for pullout test. The strips were cut in such a way so that testing can be conducted parallel to its grain.

3.1.2 Fill Material

Medium grained sand is considered as fill material in reinforced soil retaining wall as such sand is more prevalent in Guyana. The properties of sand used in the study, established from laboratory tests conducted in accordance with IS standards are presented in Table 2.

Table 2 Properties of Medium Grained River Sand

Property	Value
Angle of Internal Friction of sand (φ)	31˚
Sand– reinforcement interfacial friction (φ_μ)by pullout test (OMC & MDD condition)	43˚ (1.39φ)
Sand – reinforcement interfacial friction (φ_μ)by pullout test (fully saturated condition)	48˚ (1.55φ)

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3.2 Pullout Test for Soil – Reinforcement Interfacial Friction

For this test, timber strip is sandwiched between soil in a modified direct shear box (Pull out box), which is assembled to a conventional direct shear test apparatus. One side of the reinforcement was clamped by a pair of jaws and the other side sandwiched between sand in the modified shear box and then the reinforcement is subjected to pullout force. The pull out force is recorded by tension proving ring (refer to Figure 1).

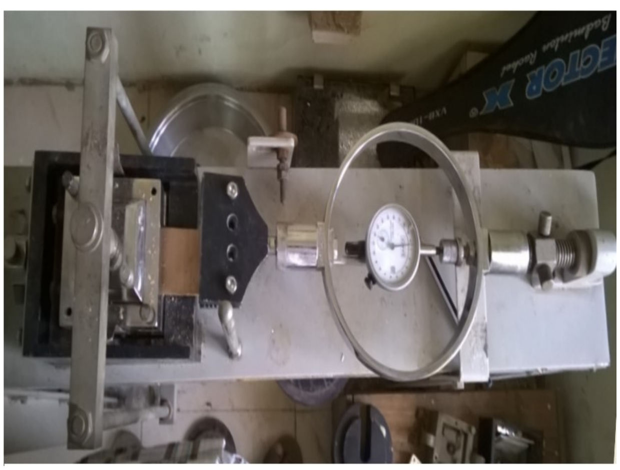

Figure 1 Greenheart timber subjected to pullout testing

Pullout tests are conducted on medium grained sand compacted at maximum dry density (MDD) and optimum moisture content (OMC). The tests are also conducted on sand in saturated state. For fully saturated condition, the sand is prepared with reinforcement, at optimum moisture content and respective MDD in the modified shear box and then soaked in water for one hour. Summary of results is presented in Table 3.

Table 3 Summary of Soil – Reinforcement Interfacial Friction Study

Property	Value
Specific gravity	2.68
Grain size analysis	
a. Gravel (%)	1
b. Sand (%)	99
c. Fines (%)	0
d. Uniformity coefficient	3.0
e. Coefficient of curvature	1.5
Plasticity characteristics	
a. Plasticity index	NP
IS Classification symbol	SP
Maximum dry unit weight (kN/m^3)	15.8
Optimum Moisture Content (%)	6.2
Shear parameters	
a. Angle of internal friction	31˚
b. Cohesion (kN/m^3)	0

4. DESIGN OF REINFORCED SOIL RETAINING WALL

Design requirements for retaining wall reinforced with greenheart timber strips and retaining wall reinforced with geogrids, for backfill heights of 4m, 6m, 8m and 10m are determined as per BS 8006(2010) with medium grained river sand as fill material. Fill, backfill and foundation material properties are considered to be the same for both greenheart timber strips and geogrid reinforcements. A surcharge (q) of 15 kN/m^2 is considered in the designs.

Use of higher interfacial friction angle than angle of internal friction of soil in design of reinforced soil retaining wall leads to failure in fill material. Hence, the value of interfacial friction between greenheart timber and medium sand is restricted to δ = 31˚, though interfacial friction angle is much higher from pullout test (see Table 3). For geogrid reinforcement, $\delta = \phi_f = 31˚$ is used, as the interlocking between grid material and soil gives rise to an angle of skin friction equal to the frictional angle of the soil itself.

Figure 2 shows reinforced soil retaining wall with earth pressure distribution diagram of backfill. Safety factors for sliding, overturning and bearing failures were checked for external stability. Sliding is initiated by the thrust of the unreinforced backfill and is most likely to occur on a plane just above or below the lowest level of reinforcement. The factor of safety against sliding is based on simple force equilibrium, as a ratio of resisting force to sliding force and is calculated using Eq. (1). Overturning is initiated by the thrust of the unreinforced backfill, causing the reinforced block to topple forward. The factor of safety is calculated from the overturning and restoring moment above the toe of the wall by using Eq. (2). Bearing failure occurs if the maximum vertical stress exerted by the reinforced soil block exceeds the bearing capacity of the underlying soil and is calculated using Eq. (3).

Safety factors for pullout and tension failures are checked for internal stability and the tie – back wedge analysis is considered for design. The upper most reinforcement is most susceptible to pullout failure and is checked by considering both the pullout capacity and the equilibrium of planar wedge mechanism through the reinforced zone. The factor of safety against tension failure was calculated using Eq. (5).

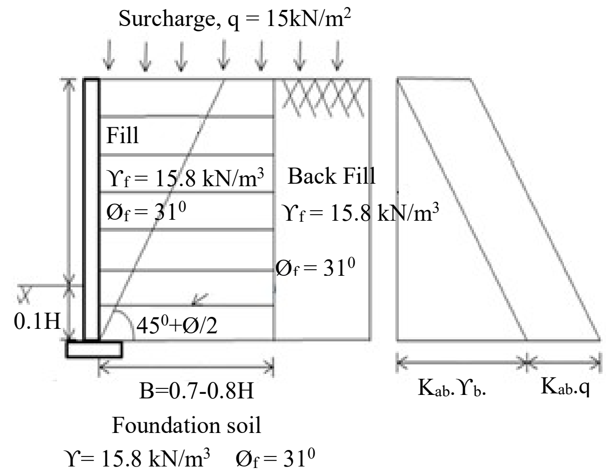

Figure 2 Reinforced soil retaining wall section with soil pressure distribution diagram

$$FS_{sliding} = \frac{\text{Resisting Force}(P_f)}{\text{Sliding Force}(P_a)} \geq 1.5 \quad (1)$$

$$FS_{overturning} = \frac{\text{Resisting Moment}(M_r)}{\text{Overturning Moment}(M_o)} \geq 2 \quad (2)$$

Bearing Failure: to avoid bearing failure,

$$q_{max} < q_a \quad (3)$$

Where,

q_{max}: Maximum pressure at base of retaining wall
q_a : Allowable bearing capacity of foundation soil

$$FS_{pullout} = \frac{\text{Force Resisting Pullout }(P_f)}{\text{Pullout Force}(P_a)} \geq 2 \quad (4)$$

$$FS_{Tension} = \frac{\text{Ultimate Tensile Strength}(T_f)}{\text{Tension Induced in Reinforcement}(T)} \geq 2 \quad (5)$$

The summary of designs for greenheart timber strips and geogrids reinforced retaining walls is presented in Table 4 and Table 5 respectively.

5. ECONOMIC EVALUATION

Economic assessment is carried out between reinforced soil retaining wall reinforced with greenheart timber strips and reinforced soil retaining wall reinforced with geogrids, with reference to Guyana. Rates are selected on the basis of Ministry of Public Works rates schedules and TenCate Miragrid® quotation given for Guyana. Cost of retaining walls is calculated for 100 m length of wall.

Construction cost using greenheart timber strips are as follow: rate for excavation of foundation soil to formation level is US $0.5 per m^3, rate for construction of leveling pad is US $250 per m^3, rate for supply and installed greenheart timber strips is US $1 per m^2, rate for supply and install concrete facing panel is US $35 per m^2, while rate for supply, lay and compact fill material is US $20 per m^3.

Construction cost using geogrids are as follow: rate for excavation of foundation soil to formation level is US $0.5 per m^3, rate for construction of leveling pad is US $250 per m^3, rate for supply and installed geogrids is US $8 per m^2, rate for supply and install concrete facing panel is US $35 per m^2, while rate for supply, lay and compact fill material is US $20 per m^3.

The summary of economic evaluation between greenheart strips and geogrids as reinforcements for reinforced soil retaining wall is presented in Table 6. Table 6 also shows percentage cost savings of greenheart strips reinforced retaining wall in comparison to geogrid reinforced wall with increased height of wall. Figure 3 shows a plot between height of retaining wall as abscissa and cost in US$ for 100 meter length of retaining wall as ordinate. From summary of cost analysis, it can be observed that as height of retaining wall increases from 4m to 10m, the construction cost savings increase from 10% to 24% by using greenheart timber strips reinforcement as alternate to geogrid reinforcements.

6. DISCUSSION

Soil – Reinforcement Interfacial Friction Study

Design of Reinforced Soil Retaining Wall

From Table 3, it is observed that, 'sand – greenheart timber' interfacial friction is higher that φ by pullout test. The value being 1.39φ, which increased to 1.55Φ. As greenheart timber is not harder than steel, aluminum and other types of strip reinforcements, the sand particles got penetrated into the greenheart timber surface under acting normal load which resulted in higher interfacial friction angle. The roughness of greenheart timber surface also contributed to high interfacial friction values. This observation goes in accordance with Shahin et al. (2013) investigation. The higher interfacial friction angle of greenwood timber strips with sand avoids slippage at interface under pull out. As a result, failure occurs in fill material at some distance from reinforcement, but not at interface.

From Table 4, Greenheart timber strips of size 350mm width x 25mm thickness is sufficient to reinforce retaining wall of heights 4m and 6m, while greenheart timber strips of size 350mm width x 50mm thickness is sufficient to reinforced retaining wall of heights 8m and 10m. All stability criteria of the reinforced soil retaining wall are satisfied by using the proposed sizes of greenheart strips. For maximum performance, the timber strips are to be placed in the direction of tensile strain (Jewell, 1996). That is, the optimum orientation of the reinforcement is given by $\theta_{opt} = (90^\circ - \varphi)$. Where, φ is the inter-granular friction of the fill material.

It is found that the width of the retaining walls decreases while using geogrids as reinforcement instead of greenheart strips. This is because the linear density ratio of reinforcement using geogrid is 100% while greenheart timber strips is only 35%. Nevertheless, greenheart timber strips is found to be more economically feasible with reference to Guyana. It is found that as height of retaining wall increases from 4m to 10m, the percentage cost saving of using greenheart timber strips increases from 10% to 24%.

Table 4 Summary of reinforced soil retaining wall with greenheart timber strips as reinforcements

Dimensions of retaining wall section		Required dimensions of strips		Horizontal spacing	Vertical spacing
Width(m)	Height(m)	Width (mm)	Thickness (mm)		
4	4	350	25	1 m	1 m
5.2	6	350	25	1 m	1 m
6.5	8	350	50	1 m	1 m
7.8	10	350	50	1 m	1 m

Table 5 Summary of reinforced soil retaining wall design with geogrid as reinforcements

Dimensions of retaining wall section		Required tensile strength (kN/m)	Vertical spacing (m)
Width (m)	Height (m)		
3.0	4.0	68	1.0
4.5	6.0	108	1.0
5.5	8.0	158	1.0
7.0	10.0	196	1.0

Table 6 Summary of cost analysis of reinforced soil retaining wall

Height of retaining wall (m)	Cost of reinforced soil retaining wall for 100m length (US $)		Cost savings using Greenheart Timber Strips (%)
	using Greenheart Timber Strips	using Geogrid	
4.0	50,970	56,360	10
6.0	91,926	108,785	16
8.0	145,390	179,950	20
10.0	210,540	276,000	24

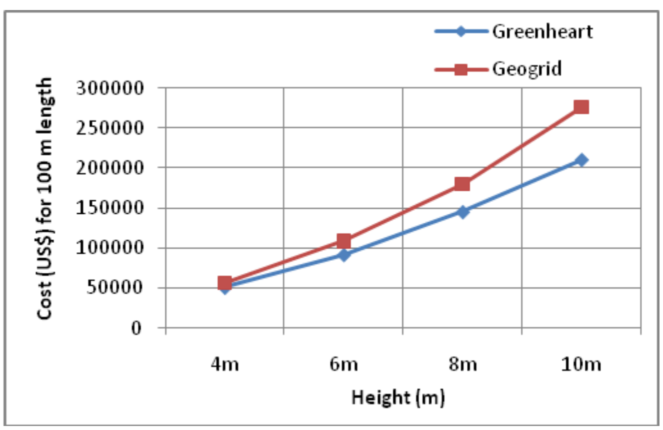

Figure 3 Plot between height of wall and cost per 100 meter length of retaining wall

7. CONCLUSIONS

Greenheart timber mobilized high interfacial frictional angle ($\Phi\mu = 1.39\Phi$) with Medium grained sand in OMC - MDD compacted condition. The value is even higher (1.55Φ) at fully saturated condition. Green heart timber mobilizes higher interfacial friction with sand in comparison to geogrids. The interface slip is unlikely under pull out as interfacial friction is more than angle of friction However, in design of reinforced soil retaining wall using greenwood timber strips, interfacial friction angle is to be restricted to angle of internal friction of fill as failure occurs in fill material instead of timber strip-fill interface.

As height of retaining wall increases from 4m to 10m, the percentage cost savings of reinforced soil retaining wall using greenheart timber strips reinforcement increased from 10% to 24% in comparison to geogrid reinforcement. Hence, greenheart timber strips may be advantageously used as reinforcement for reinforced soil retaining walls in Guyana.

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