Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Stabilisation of natural slopes using natural plant root as reinforcing agent

R. Gobinath [a,*], G.P. Ganapathy [b], I.I. Akinwumi [c]

[a] Department of Civil Engineering, S R Engineering College, Telangana, India
[b] CDMM, VIT, Vellore, India
[c] Department of Civil Engineering, Covenant University, Nigeria

A R T I C L E I N F O

Article history:
Received 31 May 2020
Received in revised form 30 July 2020
Accepted 8 August 2020
Available online xxxx

Keywords:
Grass root
Shear strength
Permeability
Bio engineering

A B S T R A C T

Soil bioengineering is the concept of utilizing plants, including its roots, to strengthen or stabilize soils with poor engineering properties such as soils in natural and manmade slopes. This technique is widely used in many countries and is also practised in India. Most of the research works done related to soil bio engineering are by ecological researchers, geotechnical research works related to utilizing the plant roots as reinforcement are few in India. In this research works, an attempt is made to study the strength variation in a landslide-affected soil by stabilizing the soil with plant roots obtained from readily available plants in the study area. The roots were obtained and a particular root mass (Lemon grass root) was introduced in the soil and the geotechnical property changes were verified. It was found that the incorporation of the plant roots in the soil matrix improved the stability of the soil. Consequently, the plant roots studied can be cheap materials for improving the stability of slopes, especially in landslide-affected areas.

1. Introduction

Certain materials are strong in compression, others in tension, but not many materials are capable of withstanding shear forces. Soils most times fail when they experience shearing. It is believed that the shear strength of soil is insignificant compared to its bearing capacity and hence a need arises to improve the strength of the soil via convention and unconventional ways. Soil improvement is important while designing geosystems, i.e. slopes, dams, embankments and hydraulic barriers, where tensile cracks are likely to occur. Addition of discrete fibre reinforcement to a soil to improve its shear strength is an unconventional technique to improve soil mechanical behavior. Though the mechanical behavior of external fiber reinforced soil has been studied extensively, the effect of plant root fibre as a reinforcement of soils on its geotechnical properties are is not yet well ascertained [2,5,7]. Figs. 1-8.

1.1. Soil reinforcement – A natural way

Soil reinforcement is an effective and reliable technique for improving strength and stability of soils. Several studies have been conducted to investigate the influence of randomly-oriented discrete inclusions (fibers, mesh elements, waste material e.g. plastic strips, tire chips, etc.) on highly compressible clayey soils including soils that are prone to landslides [3,7]. Sustainable development concept, which is recently revolutionizing the way research works are conducted is focusing on utilizing the natural materials by replacing harmful manmade materials in various aspects. It is a balancing act between the fulfillment of human needs and the protection of the natural environment, the use of natural fibers such as fibers, coir, jute, plant roots in geotechnical applications is highly desirable. Not only artificial materials can be used as reinforcement but the plant roots that are available naturally can also be used for reinforcing the soil both temporarily and permanently, this is equivalent to reinforcing soil by using coir based materials. Previous research works conducted proved that the inclusion of fibers increases strength, stiffness, reduces the compressibility and swell potential and adds more durability and stability to the soil. Also concerned with the hydraulic behavior of soils, it was

* Corresponding author.
E-mail address: gobinathdpi@gmail.com (R. Gobinath).

https://doi.org/10.1016/j.matpr.2020.08.227
2214-7853/

Fig. 1. a) Slope failed area from where soil is collected b) Soil samples.

Fig. 2. Plant root collection.

Fig. 3. Image showing the soil sample with soil and root.

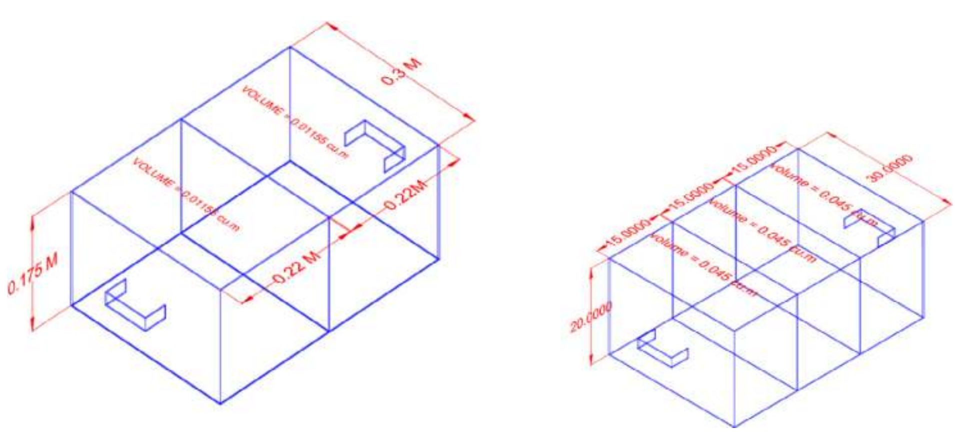

Fig. 4. Specially designed mould for the work.

Fig. 5. Sample preparation for strength tests.

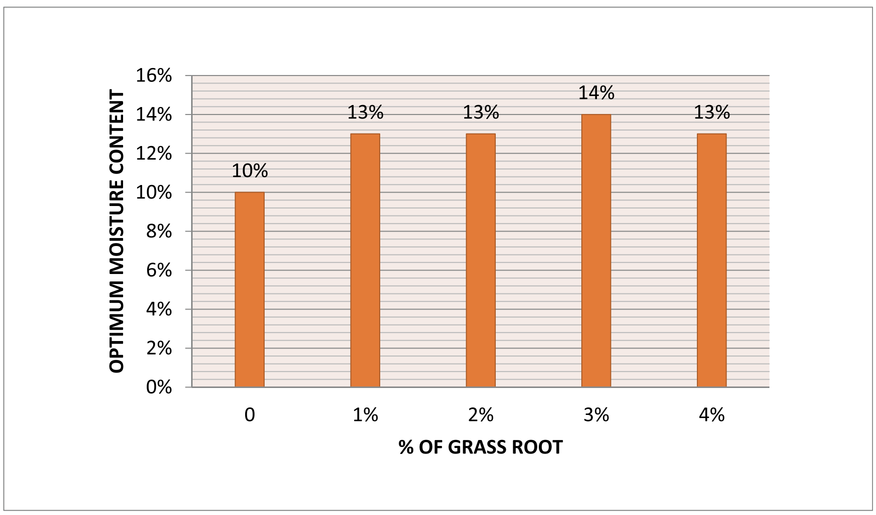

Fig. 6. The effect of OMC with the addition of various percentage of fibers.

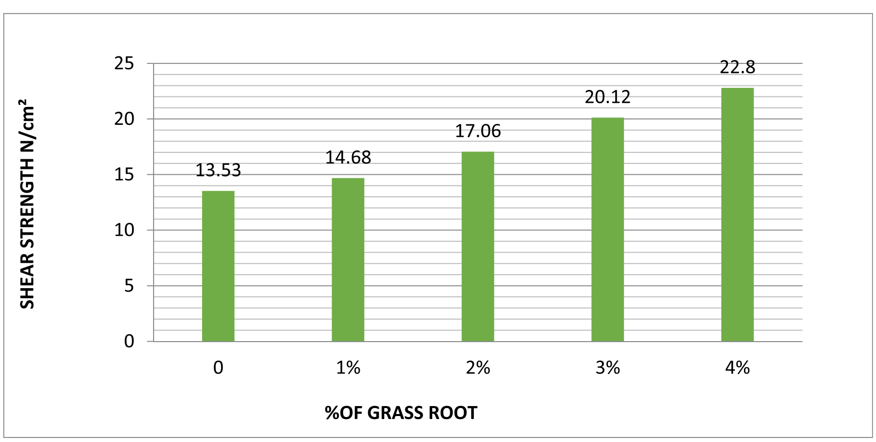

Fig. 7. The effect of Shear strength with the addition of various percentage of fibers.

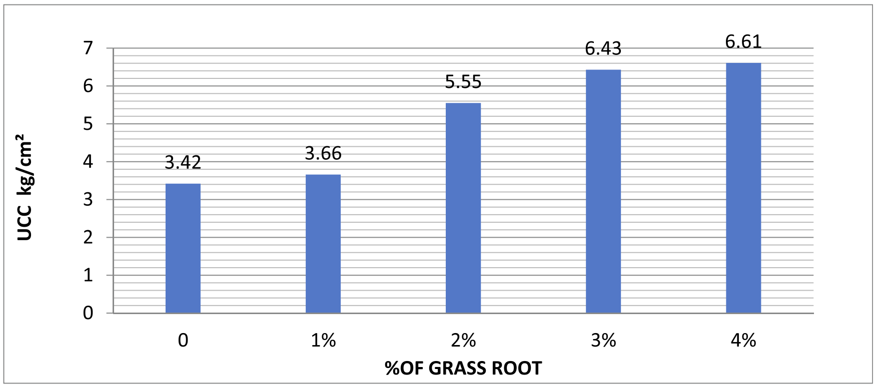

Fig. 8. The effect of UCC with the addition of various percentage of fibers.

observed that addition of fibers reduces the seepage velocity of plain soil considerably and thus increase piping resistance.

1.2. Landslide mitigation via natural methods

Shallow landslides and slope failure are serious problems around the world, including in India, where bare soils are assailable to failure through intensive rainstorm and anthropogenic activities add more stress to this problem. The naturally available slopes are protected by plants. These plants protect the surface from rain splash and their roots help to bind the soil fully. Research shows that along a potential slip surface, vegetation (tree), depending on their location, may promote and inhibit slope failure [1,7,4,6].

2. Materials and methods

2.1. Soil sample collection and preparation

Soil samples were collected from landslide affected area in Nilgris district (Fig. 1). Sampling was done as per Indian standard sampling procedures. The collected soil samples were well-packed in plastic bags enabling them for transportation without affecting their natural moisture content. The soil samples collected were transported to the laboratory for the geotechnical investigation.

In the laboratory the collected soil was air dried, crushed and passed through 2.36 mm sieve for the removal of gravel portion of the soil. The soil was then tested for index properties using Indian standard testing procedures laid in SP 36- Part 1 (Compendium of Soil mechanics) and the soil classification was done as per IS 1498:1970 using the plasticity chart. While mixing the fibers, the reinforced soil specimens were prepared by hand, by mixing dry soil, distilled water and fibres. During the mixing process, the required amount of water was added to the soil prior to adding the fibres. Fibres were mixed manually with the wet soil at small increments. Particular care was taken to achieve satisfactory uniform mixtures. Prior to compaction, the prepared mixtures were conserved in air-proof bags for two days for the purpose of moisture homogenization.

2.1.1. Properties of soil

Index properties of the soil was studied as per the procedure of Indian standards (IS 2720) and the Table 1 presents the various values of the natural soil properties. Permeability of the soil sample was studied in various soil densities such as 1200 kg/m^3, 1450 kg/m^3, 1600 kg/m^3 to validate the exact soil condition in the field Table 2.

2.2. Plant root collection

To facilitate the study and to ascertain the results accurately the native plants that are available in the Nilgris district (Fig. 2) was used throughout this study. Some of the plant species that were selected for the root reinforcement studies are

Table 1
Properties of soil sample.

S. No	Soil properties		Result
1.	Uniformity coefficient (Cu)		4.848
2.	Coefficient of curvature (Cc)		1.065
3.	Liquid limit		23.37%
4.	Plastic limit		10%
6.	Plasticity index		13.37%
7.	Liquidity index		6.667%
8.	Consistency index		93.3%
9.	Bulk density		2.12 g/cm^3
10.	Dry density		1.93 g/cm^3
11.	OMC		10%
12.	Permeability test-Falling head (kg/m^3)	1200	0.067 mm/sec
		1450	0.050 mm/sec
		1600	0.0192 mm/sec
13	Total stress		9.03 N/cm^2
14	Shear strength		13.53 N/cm^2
15	Unconfined Compressive Strength		3.42 N/cm^2
16	Specific gravity		2.6
17	Saturation ratio		49%

Table 2
Strength variation after addition of fibers SL.NO.

	Property		% of grass root			
			1%	2%	3%	4%
1	OMC	12	13	13	14	13
2	UCC N/cm² (1200 kg/m³)	3.42	3.6	5.55	6.43	6.61
3	Direct shear test N/cm² (1200 kg/m³)	13.53	14.6	17.06	20.12	22.80
4	Permeability mm/sec					
	1200 kg/m³	0.067	0.056	0.051	0.049	0.047
	1450 kg/m³	0.050	0.040	0.024	0.023	0.022
	1600 kg/m³	0.019	0.01	0.010	0.020	0.019

1. Lemon grass – Cymbopogon citratus
2. Love grass – E. cynosuroides
3. Vettiver – Chrysopogon zizanioides

Plant collection was done by the removal of subsoil using soil removal tools without affecting the soil surrounding the roots of the plants. The plants were then covered in plastic sheets and transported to the laboratory carefully without affecting the root-soil mass. The roots were then separated (Fig. 3) only in the required quantity, the remaining portion was watered to keep the plants alive until the testing was completed. This method allowed the roots to continue growing during the period of the experimentation.

2.3. Experimentation procedure

The standard procedure laid down in the Indian standards was adopted for the testing, the index properties of the soil was initially studied. The roots were prepared with various aspect ratio by cutting down the various portions of the root from the plants. They were washed with distilled water, kept dried in an oven to find the root bio mass. The obtained root were then prepared with various aspect ratios and kept in plastic containers prior to the addition of fibers in the soil. All tests were conducted in a specially designed mould (Fig. 4) which can accommodate 0.2 m^3 of soil sample in a single stretch. The soil sample was prepared in the mould of dimension 1 m $\times$ 1 m $\times$ 0.25 m size, this kind of preparation facilitated the addition of constant water and also helped in the maturation of water in soil. The soil was placed in the mould and compacted with standard energy equivalent to the standard proctor value and after compaction it was covered with plastic sheet and kept for 6 h for even distribution of its water content. Cores were cut from the soil prepared using specially designed core samplers of various capacities and tests were done on the undisturbed soil samples to ascertain accurate values. Also, it is to be noted that plant roots do not have consistent diameter and hence finding aspect ratio is not at all possible in any plants. The roots have varying diameter from top to bottom and an average diameter only can be used, yet the strength of the root is not proportional to its diameter but to the cellulose content which will be uniform throughout the plant. In this study the roots selected were of mostly even diameter and not accurately common throughout the length.

3. Results and discussion

Tests were conducted after proper maturation period using Indian standard test procedure. The shear strength test (Fig. 5) was conducted with shear controlled undrained pattern. Unconfined test was conducted in the stress controlled, undrained pattern. Permeability and hydraulic characteristics were obtained using falling head permeameter. Plant roots in single aspect ratio was used throughout the study, the length and the diameter of the root was measured using digital Vernier caliper (Mitutoyo). The roots were washed and immersed in water for at least 3–4 h before addition of fibers in the soil. The soil- root matrix is prepared by using hand mixing to enable thorough mixing of the roots across the soil matrix. The soil was kept in a specially-designed soil mould which enabled undisturbed soil testing. The results obtained were given in Table 2 which shows the variation of

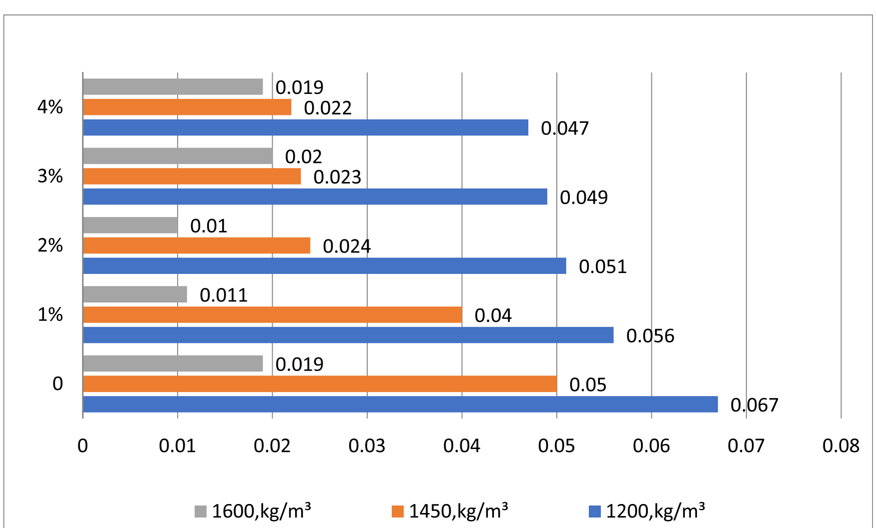

Fig. 9. The effect of Permeability with the addition of various percentage of fibers.

strength and hydraulic parameters with and without addition of roots.

3.1. Effect on optimum moisture content

Optimum moisture content of the soil was affected by the addition of roots. This is an important parameters concerned with the consolidation and compaction characteristics of soil. It was found that the addition of 2–4% of roots by weight to the soil affected the OMC value and increased it to 13% from 10% (Fig. 6). This is a considerable increase in terms of water quantity required to compact the soil. This is mainly attributed to the larger surface area of the roots which absorbs more water during the mixing and maturation. Unlike natural fibers or ash used in several studies, roots have less impact on water absorption. Yet, the increase in OMC was obtained in this study which may be of several other attributes including the channels the roots created in the soil.

This also increased the weight of root mass and hence provides more stability and strength to the soil-matrix.

3.2. Effect on shear strength

Soils usually fail mostly due to shear failure and thus its mandatory to initiate the shear strength. In this study, it was found that there was considerable increase in the shear strength with an increase in the percentage of root mass in the soil (Figs. 7,8). The shear strength was studied for the undisturbed soil samples and hence it can be ascertained that the shear strength increase was purely attributed to the roots tensile strength and the root bio mass.

3.3. Effect on permeability

Fig. 9 shows the effect of root addition on the permeability of the soil. The permeability was steadily decreasing with the increase in the root content. This may be due to two factors: firstly, due to the density variation that occurred because of root penetration. The addition of 4% reduced the permeability to half of its original value and also added more strength to soil due to this. Several researchers had also supported this outcome even in the field studies that the root growth inside soil compacts the soil and reduces the permeability considerably.

4. Conclusion

In this study, it was found that addition of roots as a fiber matrix is a viable solution for increasing both strength and stability characteristics. The permeability of the soil steadily decreased with the increasing root content, which was as a result of increased density and shearing resistance of the soil matrix. The study was conducted with varying density to verify the accuracy of reduction in hydraulic properties and it was found that the roots also adds up more reduction in the permeability other than densification of soil. Also, it was found that the roots take up some amount of water added in the soil particles and thus results in increased OMC values in soils with higher root percentage. This agrees up with the results provided by other researchers who used various other natural fibers for increasing the shearing resistance of soils. Shearing resistance grows steadily with the increase in the root content in the soil. The roots creates a fiber matrix and with the increase in matrix density and the variation of fibers the strength value steadily increases. The acute problem that may be faced by the addition of root as fibers is the degradation of roots inside the soil after certain period, but this case is common for all types of natural fibers added to soils. Concerned with the soil-root matrix the humus that may be produced due to the composite degradation of root-soil matrix may add more stability. Coir fibers added to soils for river bank protection in many research works proved this. Thus, it is evident that usage of natural plant roots in various aspect ratios can be utilized for soil reinforcement.

CRediT authorship contribution statement

R. Gobinath: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing - original draft, Writing - review & editing. **G.P. Ganapathy:** Supervision, Validation, Funding acquisition. **I.I. Akinwumi:** Writing - review & editing, Investigation, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Habibah Lateh, Nazi Avani, Ghasem Habibi Bibalani, Effect of acacia mangium root properties onshallow landslide and slope stability, J. Life Sci. Technol. 1 (2) (2013).
[2] Jian Li, Chaosheng Tang, Deying Wang, Xiangjun Peib, Bin Shi, Effect of discrete fibre reinforcement on soil tensile strength, J. Rock Mech. Geotech. Eng. 6 (2014) 133–137.
[3] Parag M. Chaple, A.I. Dhatrak, Performance of coir fiber reinforced clayey soil, Int. J. Eng. Sci. 2 (4) (2013) 54–64.
[4] Kumar K. Rajesh, R. Gobinath, G. Shyamal, Emelec Viloriac, Noel Varelac, Free thaw resistance of stabilized and fiber-reinforced soil vulnerable to landslides, Mater. Today Proc. 27 (1) (2020) 664–670.
[5] Ravindran Gobinath, Isaac Ibukun Akinwumi, Olaniyi Diran Afolayan, Saravana Karthikeyan, Murugasamu Manojkumar, Sivaraj Gowtham, Ayyasamy Manikandan, Banana Fibre-Reinforcement of a Soil Stabilized with Sodium Silicate, Silicon 12 (2020) 357–363, https://doi.org/10.1007/s12633-019-00124-6.
[6] Prabhanjan.N Gobinath.R, Raja.G, Prasath.E, Sahithi.G, Seismic Response of root reinforced soil slope at Nilgris district Soil, Tamilnadu, International Journal of Scientific & Technology Research,9(2), 3666 – 3674
[7] R.G.P. Gobinath, Isaac I. Ganapathy, E. Akinwumi, G. Prasath, T. Raja, G. Shyamala Prakash, Soil erosion protection on hilly regions using plant roots: an experimental insight, in: P. Shit, H. Pourghasemi, G. Bhunia (Eds.), Gully Erosion Studies from India and Surrounding Regions. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development), Springer, Cham, 2020.

Further Reading

[1] BIS, Methods of test for soils: Determination of triaxial strength (first revision), IS 2720: Part 11, Bureau of Indian Standards, New Delhi, 1971.
[2] BIS, Methods of test for soils: Determination of unconfined compressive strength (first revision), IS 2720: Part 10, Bureau of Indian Standards, New Delhi, 1973.
[3] BIS, Methods of Test for Soils: Determination of Water Content-dry Density Relation Using Light Compaction (second revision), IS 2720: Part 7, Bureau of Indian Standards, New Delhi, 1980.
[4] BIS, Methods of Test for Soils: Determination of Liquid Limit and Plastic Limit (second revision), IS 2720: Part 5, Bureau of Indian Standards, New Delhi, 1985.
[5] BIS, Methods of Test for Soils: Determination of Consolidation (second revision), IS 2720: Part 15, Bureau of Indian Standards, New Delhi, 1986.
[6] BMTPC, Landslide Hazard Zonation Atlas of India, Published by Building Materials and technology Promotion Council, Government of India and Anna University, Chennai, 2003.
[7] M. Dharani, R. Gobinath, M. Vikashini, S. Lavanyaa, V. Banupriya, Stabilization of landslide affected soil using silica fume glass fiber powder and sodium silicate, Int. J. Construct. Eng. Plann. (2017) 1–7.
[8] Ganapathy and Jothimani Ponnusamy, "Hazard Estimation and First Level Landslide Risk Mapping-A Case Study, Burlier Area of the Nilgiris District in Western Ghats," Abstracts of the "Geomatics 2009" National Conference, Dehradun, Feb 4-6, 2009.
[9] G.P. Ganapathy, R. Gobinath, I.I. Akinwumi, S. Kovendiran, M. Thangaraj, N. Lokesh, S. Muhamed Anas, R. Arul Murugan, P. Yogeswaran, S. Hema, Bio-enzymatic stabilization of a soil having poor engineering properties, Int. J. Civil Eng. 15 (3) (2017) 401–409.

[10] Ganapathy, K. Mahendran, S.K. Sekar, Need and urgency of landslide risk planning for nilgiri district, Tamil Nadu State, India,, Int. J. Geomat. Geosci. 1 (1) (2010) 2010.
[11] R. Gobinath, G.P. Ganapathy, I.I. Akinwumi, S. Kovendiran, S. Hema, M. Thangaraj, Plasticity, strength, permeability and compressibility characteristics of black cotton soil stabilized with precipitated silica, J. Cent South. Univ. 23 (2016) 2688–2694.
[12] R. Gobinath, G.P. Ganapathy, I.I. Akinwumi, Evaluating the use of lemon grass roots for the reinforcement of a landslide-affected soil from Nilgris district Tamil Nadu, India, J. Mater. Environ. Sci. 6 (10) (2015) 2681–2687.
[13] Goldsmith, Wendi 1993. Lakeside Bioengineering, Land and Water Magazine March/April 1993.
[14] Gray, Donald H. and Leiser, Andrew T. 1989. Biotechnical Slope Protection and Erosion Control. Krieger Publishing Company. Santa, Calista R. Coir an Abundant Natural Fiber Resources, Land and Water Magazine May/June 1994.
[15] Karle, Kenneth E. 2003. Evaluation of Bioengineered Stream Bank Stabilization in Alaska. Alaska Department of Transportation Report FHWA-AK-RD-03-03, Juneau, Alaska.
[16] Lewis L., Soil Bioengineering - An Alternative for Roadside Management, A Practical Guide, 2000.
[17] NDMA, ''National Disaster Management Guidelines: Management of Landslides and Snow Avalanches," National Disaster Management Authority, Government of India, June 2009.
[18] Rajarathnam S. and Ganapathy G.P., ''Landslide Hazard Zonation of India, a GIS Approach," Proceedings of the First India Disaster Management Congress, New Delhi, 29-30 November 2006.
[19] Ravindran Gobinath, Isaac Ibukun Akinwumi, Olaniyi Diran, Afolayan, Saravana Karthikeyan Murugasamu Manojkumar, Sivaraj Gowtham, Ayyasamy, Manikandan, (2018), Banana Fibre-Reinforcement of a Soil Stabilized with Sodium Silicate, Silicon, doi.org/10.1007/s12633-019-00124-6a.
[20] Gobinath Ravindran, Ganapathy Ganapathy, Isaac Akinwumi, S. Kovendiran, S. Hema, M. Thangaraj, Plasticity, strength, permeability and compressibility characteristics of black cotton soil stabilized with precipitated silica, J. Central S. Univ. 23 (2016) 2688–2694, https://doi.org/10.1007/s11771-016-3330-7.
[21] Santha, Lanka 2003. Design Guidelines for Next Generation Soil Bioengineering Designs. International Erosion Control Association 2003 Proceedings.
[22] Santha, Lanka. and Santha, Calista R. Effective Utilization of Fully Matured Grass in Erosion Control., International Erosion Control Association 1995 Proceedings.
[23] Santha, Lanka. and Santha, Calista R. Standards for Coir Erosion and Sedimentation Control Products., International Erosion Control Association 1995 Proceedings.
[24] Thanavelu and Chandrasekaran, ''Geotechnical Assessment of November 2006 landslides in the Nilgiris Tamil Nadu," Abstract Volume: Proceedings of the National Seminar on Challenges in Engineering Geology, 03rd to 05th December 2008.
[25] WSDOT, ''Road Side Manual, M25-30.01," Washington State Department of Transportation Development Division, Design Office, Olympia, WA 98504-7329, pp.314, July 2012. Bhoop Singh, DST's initiatives on ''Landslide Hazard Mitigation, Available: http://gisdevelopment.net/application/natural_hazards/landslides/ma05297pf.htm, 2006.
[26] Gobinath.R, Raja.G, Prasath.E, Shyamala.G, Amelec Viloria, Noel Varela, Studies on strength characteristics of black cotton soil by using novel SiO2 combination as a stabilizing agent, Materials Today: Proceedings Volume 27, Part 1, 2020, Pages 657–663.