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# Enhancement of River Bank Stability by *Hibiscus tiliaceus* Root Reinforcement: A Nature-based Solution

**L.G.C. Madhushan, U.P. Nawagamuwa and M.D.J.P. Wickramasooriya**

**Abstract:** Riverbank protection is becoming a significant environmental challenge in Sri Lanka. Although structural solutions have been commonly applied for slope stabilisation, many approaches using Nature-based Solutions (NbS) have been employed by humans for a long time to enhance riverbank stability as sustainable and ecologically practicable solutions. As an NbS, this research investigates the mechanical stabilisation potential of *Hibiscus tiliaceus* through field assessments and numerical modelling. *Hibiscus tiliaceus* is a native species that has been traditionally used in Sri Lanka. Field observations along the Kelani River (Hanwella to Kaduwela) showed that sections with *Hibiscus tiliaceus* displayed enhanced stability compared to non-vegetated areas. Numerical analysis was conducted using SLOPE/W software, simulating three slope geometries (1V:1H, 1V:1.5H, 1V:2H) under four hydraulic conditions: low flow, mid flow, full flow, and rapid drawdown in the river. The root reinforcement was modelled by incorporating depth-varying apparent cohesion based on literature-derived parameters. Results showed that vegetated slopes have consistently higher Factors of Safety (FoS), particularly on steep slopes under rapid drawdown. The findings highlight the importance of *Hibiscus tiliaceus* as a sustainable, cost-effective NbS for riverbank protection and offer a pathway for integrating tree vegetation into riverbank failure control strategies in Sri Lanka.

**Keywords:** Bioengineering, Mechanical reinforcement, Riverbank protection, Root cohesion, Slope stability

## 1. Introduction

In countries such as Sri Lanka, where rivers serve as critical lifelines for both human populations and ecological systems, riverbank failures have developed as a growing concern, particularly in regions with high land value. These failures are often driven by dynamic changes in river morphology resulting from seasonal flooding, intense rainfall, deforestation, and unregulated human activities such as sand mining. The consequences are the loss of fertile agricultural land, damage to infrastructure, and the disruption of riverine ecosystems.

Even though the riverbank protection methods, such as concrete embankments, gabion walls, and boulder riprap, are effective to some extent, they are less sustainable in terms of financial cost, environmental friendliness, and rigid design. Therefore, there has been increasing global attention toward Nature-based Solutions (NbS), which utilize natural ecosystems to provide cost-effective and environmentally friendly alternatives [1].

In the context of slope stabilization by roots, Nature-based Solutions (NbS) primarily operate through three mechanisms [2]:

1. Mechanical reinforcement provided by root systems
2. Dissipation of excess pore water pressure
3. Induction of matric suction in the root zone

The Kelani River, which flows along the northern boundary of the Colombo District, particularly from Awissawella to Colombo (Figure 1), traverses an area characterized by high population density and land value and is severely affected by riverbank failures.

*Eng. L.G.C. Madhushan, AMIE (SL), B.Sc. Eng. (Hons) (Moratuwa),*
*Email:madhushanlc.20@uom.lk*
*ORCID ID: http://orcid.org/*0009-0005-1854-764X
***Eng. (Prof.) U.P. Nawagamuwa**, CEng, FIE (SL), B.Sc.Eng.Hons(Moratuwa), MEng(AIT), DrEng(YNU), Professor, Department of Civil Engineering, University of Moratuwa, Sri Lanka*
*Email:udeni@uom.lk*
*ORCID ID: http://orcid.org/*0000-0002-7088-0694
***Eng. M.D.J.P. Wickramasooriya**, IntPE(SL), FIE(SL), C.Eng(SL), B.Sc.Eng.Hons (Moratuwa) , M.Sc.Eng. (Peradeniya), MIEAust, CPEng(Australia), APEC, NER, IntPE(Aus), Irrigation Engineer, Irrigation Department, Sri Lanka.*
*Email:wickramasooriyamdjp.21@uom.lk*
*ORCID ID: http://orcid.org/*0000-0002-0122-4992

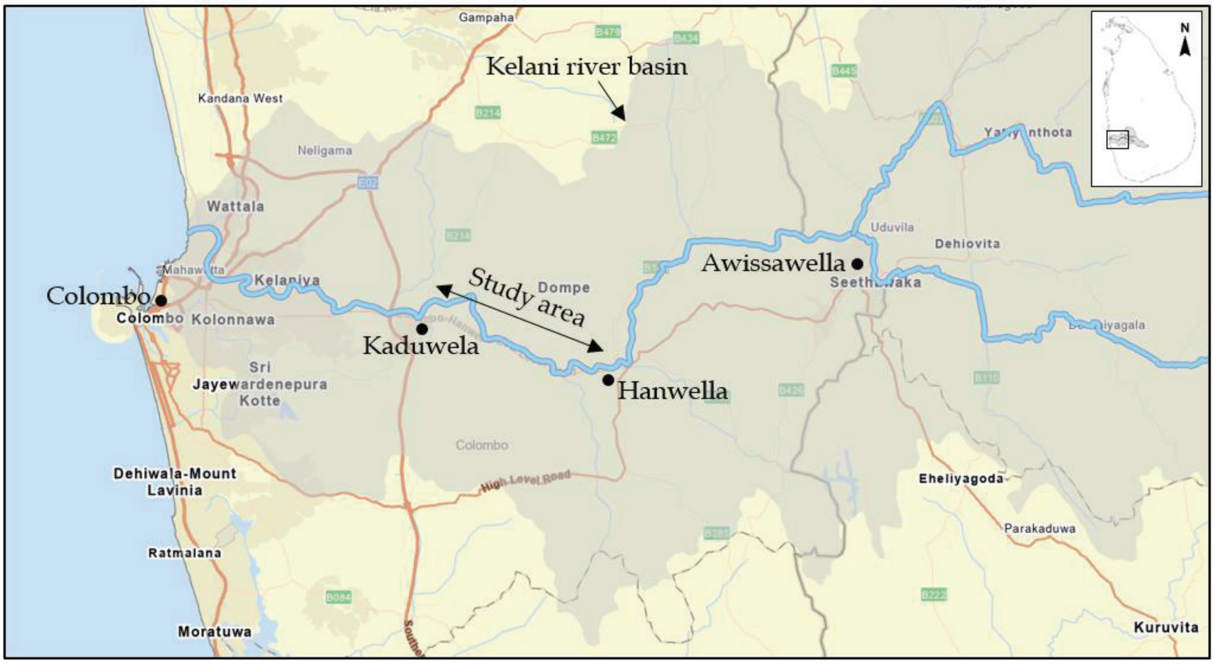


**Figure 1 – Study area along the Kelani River from Kaduwela to Hanwella**

Although Sri Lanka is rich in native vegetation and diverse tree species, there remains a significant lack of technical data and quantitative research on the mechanical stabilization contributions of these species through their root systems. *Hibiscus tiliaceus* ("*Wal Beli*" or "*Belipatta*" in Sinhalese) was identified as one of the common tree species in the riverine environment of the lower Kelani River basin, from Hanwella to the river mouth, and has proven effective in mitigating riverbank failures and enhancing bank stability. Furthermore, field inspections revealed that riverine dwellers have actively used *Hibiscus tiliaceus* in failed riverbank sections (Figure 2) along the Kelani River to improve riverbank stability.

**Figure 2 – Live poles of *Hibiscus tiliaceus* planted on a failed riverbank section**

This research aims to evaluate the mechanical effects of the *Hibiscus tiliaceus* root reinforcement system using evidence from the literature, field observations, and numerical modelling conducted with SLOPE/W software. Specifically, the study examines how root-induced cohesion, arising from root tensile strength and the Root Area Ratio (RAR), enhances riverbank stability, while deliberately excluding hydrological effects associated with roots. Furthermore, advances in scientific research in this area support the development of sustainable river management strategies through Nature-based Solutions (NbS) as cost-effective riverbank protection methods and provide pathways for integrating native vegetation into riverbank failure mitigation strategies in Sri Lanka.

## 2. Literature Review

### 2.1 Nature-based Solutions

Nature-based Solutions (NbS) are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [1]. This definition emphasizes the multifunctional role of NbS in addressing environmental, social, and economic challenges. The goal of NbS is "to support the achievement of society's development goals and safeguard human well-being in ways that reflect cultural and societal values and enhance the resilience of ecosystems, their capacity for renewal, and the provision of services; NbS are designed to address major social challenges, such as food security, climate change, water security, human health, disaster risk, and social and economic development" [1].

In the context of slope stabilization and the protection of riverine environments, Nature-based Solutions (NbS) encompass interventions such as vegetative slope stabilization, riparian buffer establishment, floodplain restoration, and green infrastructure planning, all of which enhance ecosystem resilience while reducing erosion and slope failures. Moreover, NbS typically require lower maintenance costs, are socially inclusive, and align with international sustainability frameworks such as the United Nations Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction.

### 2.2 Reinforcement of Soil by Roots

Tree roots play a major role in enhancing slope stability, particularly in riverine environments. Acting as natural reinforcements, they improve soil structure by increasing shear strength and reducing the risk of shallow landslides and surface erosion.

Numerous studies have identified root reinforcement as a key mechanism in soil stabilization by vegetation. Critical parameters influencing root reinforcement include root tensile strength, the Root Area Ratio (RAR), and root failure mechanisms. Furthermore, Operstein and Frydman [3] identified five major factors that significantly influence the shear resistance of root-permeated soils: the quantity and directional distribution of roots, root tensile strength, Young's modulus of roots, the inherent shear strength of the soil, and soil–root interaction characteristics.

In general, the increase in soil shear strength due to root reinforcement can be estimated using the extended Mohr–Coulomb equation [4].

$$\tau = c + \sigma_N tan\varphi + \Delta\tau \qquad \ldots (1)$$

where,
$\tau$ = shear strength of the soil
c = cohesion of the soil
$\varphi$ = friction angle
$\sigma_N$ = normal stress
$\Delta\tau$ = increment of shear strength due to root reinforcement

Furthermore, Waldron [5] proposed the following equation to determine the increase in shear strength caused by inclined roots, it is defined as

$$t_r = T_r \frac{A_R}{A} \qquad \ldots (2)$$

where,
$t_r$ = increment of shear strength due to inclined roots
$T_r$ = tensile strength of roots
$A_R$ = Area of roots
$A$ = Area of the soil

Moreover, Docker & Hubble [6] conducted many in-situ field shear tests for tree species and derived the following empirical relationship for the shear strength increment ($\Delta$S).

$$\Delta S = \alpha\ (RAR) + \beta \qquad \ldots (3)$$

Here, RAR denotes the Root Area Ratio, defined as the ratio of the cumulative cross-sectional area of roots to the cross-sectional area of the soil profile intersected by the roots, while $\alpha$ and $\beta$ are empirical constants that vary among tree species. Tree roots strongly influence soil suction; therefore, the increment in shear strength ($\Delta\tau$) is attributed to an increase in matric suction induced by vegetation.

However, the above empirical relationship does not explicitly account for suction generated through transpiration. Moreover, its applicability to different root systems with varying orientations is limited, as the only variable considered in the formulation is the RAR.

### 2.3 Case Studies on Root Reinforcement

Numerous studies have demonstrated the effectiveness of root reinforcement in slope stabilization. Experimental investigations and modelling approaches have helped quantify the contribution of roots to the shear strength of slopes.

Pallewattha et al. [7] conducted a comprehensive study on the root systems of Eucalyptus botryoides, performing tensile strength tests using an INSTRON testing system. Similarly, Nawagamuwa et al. [8] examined the tensile properties of tea plant roots using a conventional yarn-testing machine and a traditional tensiometer.

Chok et al. [9] developed a finite element code to analyze the impact of vegetation on slope stability. Their results showed that the factor of safety increased by 19% when vegetation was present across the entire ground surface with a slope inclination of 2H:1V (26.6° to the horizontal), for soil with a cohesion of 1 kPa and a friction angle of 25°. Furthermore, they generated a series of stability charts that can be used to assess the influence of root reinforcement on slope stability.

Further, Fan & Chen [10] have studied *Hibiscus tiliaceus* and determined a relationship between the root diameter and the tensile strength of roots (Figure 3).

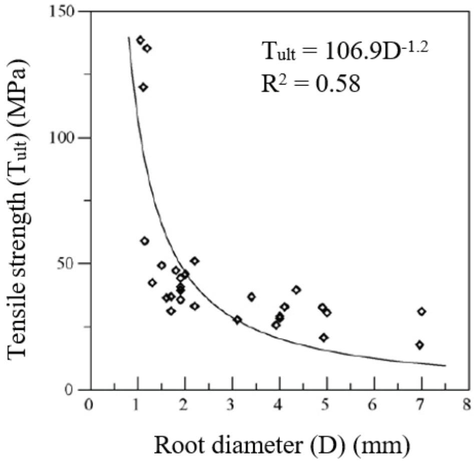


**Figure 3 – Relationship between root diameter and the tensile strength of the roots [10]**

Furthermore, Fen and Chen [10] established the relationship between the shear strength increment ($\Delta S$) and the tensile force of roots per unit area of soil ($t_R$), both based on roots intersecting the shear plane (Figure 4) and on all roots of a single plant (Figure 5).

Mafian et al. [11] conducted comprehensive research on the growth of *Hibiscus tiliaceus* and *Dillenia suffruticosa* roots when planted as live poles. They demonstrated that live poles provide a practical and economical alternative to conventional techniques for shallow slope stabilization. Furthermore, Prasad et al. [12] planted *Hibiscus tiliaceus* and *Dillenia suffruticosa* live poles in three trial strips and observed that the poles established well. They also reported that the roots of *Hibiscus tiliaceus* had grown to approximately 22% of their original length underground, with root diameters ranging from 0.5 to 5.7 mm. Their study showed a considerable increase in the factor of safety (FoS) of shallow slope failures due to the presence of *Hibiscus tiliaceus* roots.

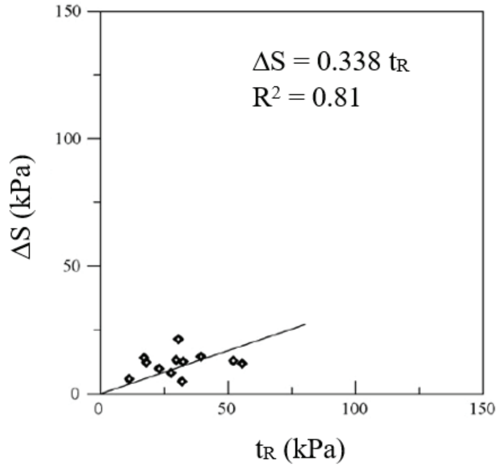


**Figure 4 – Relationship of the shear strength increment versus tensile force of roots per unit area of the soil on the basis of roots crossing the shear plane [10]**

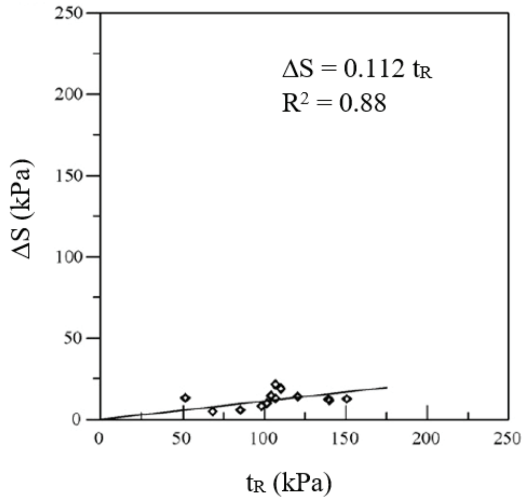


**Figure 5 – Relationship of the shear strength increment versus tensile force of roots per unit area of the soil on the basis of all roots in a single plant [10]**

## 3. Methodology

The main aim of this study is to evaluate the enhancement of the riverbank stability by the roots of *Hibiscus tiliaceus*. Initially, an area was selected in the Kelani River basin, and field inspections were carried out along with a plant survey along the riverbank. SLOPE/W software in the GeoStudio package was used for modelling riverbank stability based on the limit equilibrium method. Finally, a comparative analysis of the factors of safety (FoS) for riverbank slope failures was conducted with and without root reinforcement to evaluate the influence of vegetation on slope stability under four different hydraulic scenarios of the river.

### 3.1 Study Area

Based on the review of available reports and studies, the section from Hanwella to Kaduwela (Figure 1) was selected, as it has experienced severe riverbank failures in recent years.

A walk-through survey and preliminary field inspections were conducted at accessible locations along the Kelani riverbank, from Hanwella to Kaduwela, to identify the plant species present. This segment of the river is of critical importance due to its high density of human settlements, farmlands, and transport infrastructure. Furthermore, it represents a dynamic, high-energy river system subject to seasonal fluctuations in flow and sediment transport.

### 3.2 Selection of Plant Species

Based on field inspections along the Hanwella to Kaduwela riverbank, *Hibiscus tiliaceus* was identified as one of the common tree species utilized by riverine dwellers for riverbank protection. Consequently, *Hibiscus tiliaceus*, locally known in Sri Lanka as "*Belipatta*" or "*Walbeli*," was selected due to its proven mechanical reinforcement properties, adaptability to riparian environments (Figure 6), and suitability for bioengineering applications. This species possesses a vertical–horizontal (VH-type) root system [13], combining deep-penetrating taproots with widely spreading lateral roots.

**Figure 6 – Vegetation barrier of *Hibiscus tiliaceus* near the Kaduwela bridge**

According to Lee, Tsai & Lee [14], *Hibiscus tiliaceus* exhibits root growth lengths ranging from approximately 2.0 m to 2.5 m. Its RAR ranges from about 0.0057 to 0.0425 [10], demonstrating moderate to dense root occupation in the subsurface soil matrix (Figure 7). The tensile strength of the *Hibiscus tiliaceus* roots can typically reach between 10 and 40 MPa [10], and the root-induced apparent cohesion, which reflects the mechanical reinforcement contribution to the surrounding soil, ranges from 5 to 21.9 kPa [10].

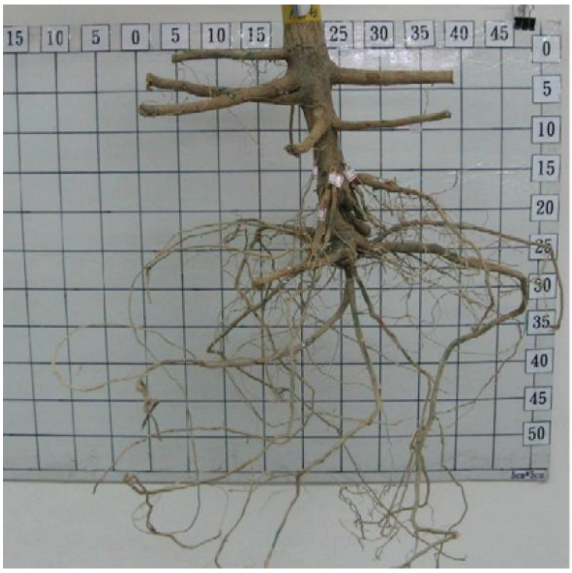


**Figure 7 – Root system of *Hibiscus tiliaceus* [10]**

Furthermore, during the field inspections, it was observed that *Hibiscus tiliaceus* is highly valued for its ease of propagation, especially through live pole techniques (Figures 2, 8 & 9). Thick branch cuttings, often measuring up to 1.5 m to 2.0 m long and 10 cm in diameter [11], can be directly inserted into the ground to establish new plants.

These cuttings have exhibited survival rates ranging from 45% to 79% [11], depending on site conditions such as soil type, moisture availability, and management practices. Once established, the plants demonstrate a moderate to fast growth rate, often attaining heights of 0.75 to 1.5 m per year under favourable tropical conditions (Figures 8 and 9) [11].

**Figure 8 – *Hibiscus tiliaceus* plant**

**Figure 9 – Well-grown *Hibiscus tiliaceus* tree**

### 3.3 Soil and Geotechnical Parameters

Soil and geotechnical parameters for this study were derived from the Geological and Geotechnical Desk Study [15] by the Ministry of Irrigation and Water Resources Management, and 21 boreholes were drilled along the Kelani River between Hanwella and Kaduwela. Investigations revealed three primary soil layers, each with distinct mechanical properties [15], and they are summarized in Table 1. This analysis considers rapid drawdown, hence, the effective parameters were not used. These parameters were incorporated into numerical models to simulate the mechanical interactions between slope materials.

#### 3.4.1 Model geometry and hydraulic conditions

The basic numerical model developed for this study (Figure 10) represented a typical cross-section of the Kelani River embankment, based on field observations and geotechnical investigation data in Table 1.

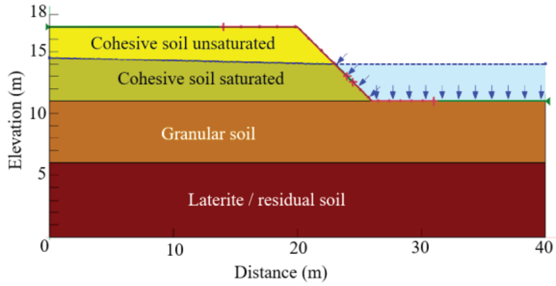


**Figure 10 - Basic river embankment model for mid-flow condition under slope 1:1**

The embankment height was selected as 6.0 m, which is a common height observed in the study area. Three slope geometries were considered based on the site observations of riverbank slopes: 1V:1H (45° to horizontal), 1V:1.5H (33.7° to horizontal), and 1V:2H (26.6° to horizontal), allowing comparison of mechanical performance across steep, moderate, and gentle slopes, respectively. The groundwater flow and river interaction were simulated by introducing a phreatic surface with a hydraulic gradient of 0.03 (Figure 10), representing typical riverbank seepage.

**Table 1 – Summary of the parameters of subsurface layers**

| Layer depth (m) | Material | Moisture content | Bulk unit weight (kN/m³) | Dry unit weight (kN/m³) | Cohesion (kPa) | Friction angle |
|---|---|---|---|---|---|---|
| 0 to 6 | Soft to firm, dark grey cohesive silty clay with high plasticity and organic matter | 36 % | 17 | 13 | 10 | 25° |
| 6 to 11 | Granular alluvium, very loose to medium dense silty clayey sand | 20 % | 18 | 13 | - | 34° |
| 11 to 17 | lateritic residual soils with mottled ferruginous clays and sandy gravels | 32 % | 18 | 14 | 50 | 36° |

### 3.4 Numerical Modelling

The SLOPE/W software in the GeoStudio package was used to model slope stability for different slope angles, and the mechanical reinforcement effect of *Hibiscus tiliaceus* roots was incorporated as a cohesion value into the SLOPE/W model.

To represent the dynamic hydraulic conditions of the Kelani River, four distinct water level scenarios were considered:

1. Low flow: river water level 0.5 m above the riverbed
2. Mid flow: river water level 3 m above the riverbed
3. Full flow: river water level 6 m above the riverbed (full discharge)

4. Rapid drawdown: river water level decreases from 6 m to 3 m above the riverbed

Each scenario was applied to the slope models for the selected slopes, both with and without vegetative reinforcement, enabling a comparative analysis of slope failures.

### 3.4.2 Vegetation modelling and mechanical inputs

The mechanical contribution of *Hibiscus tiliaceus* roots was incorporated by adding depth-varying apparent cohesion zones. The root influence depth was selected as 4 m in the cohesive soil layer (Figure 11) at the top, and they are layered as in Table 2. Apparent cohesion values due to *Hibiscus tiliaceus* roots were added to each layer based on the results by Fan & Chen [10]. The other soil parameters were chosen from the in situ & laboratory tests, with the assumption that the apparent cohesion due to *Hibiscus tiliaceus* remains unchanged.

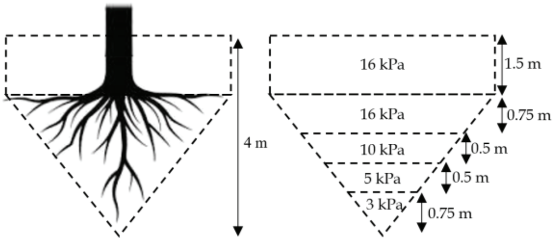


**Figure 11 – Variation of the apparent cohesion due to roots with depth**

**Table 2 – Apparent cohesion due to roots**

| Depth from ground | Apparent cohesion |
|---|---|
| 0 m to 1.5 m | 16 kPa |
| 1.5 m to 2.25 m | 16 kPa |
| 2.25 m to 2.75 m | 10 kPa |
| 2.75 m to 3.25 m | 5 kPa |
| 3.25 m to 4 m | 3 kPa |

These derived apparent cohesion values were added to the topsoil layer to demonstrate the effect of the roots, and the parameters applied in the model with the effect of *Hibiscus tiliaceus* roots in each layer are tabulated in Table 3.

Additionally, the self-weight of the vegetation canopy and branches was incorporated as a surface surcharge of 5 $kNm^{-2}$, representing the weight over a typical vegetation grid (Figure 12). Together, these inputs allowed the model to realistically simulate the mechanical reinforcement effects of *Hibiscus tiliaceus* trees.

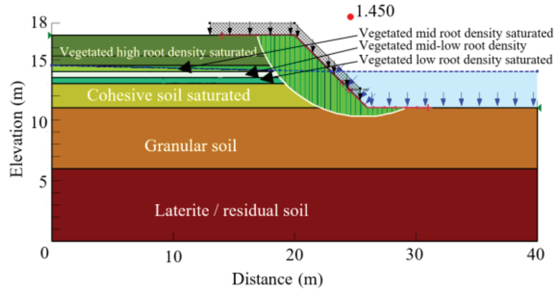


**Figure 12 - Vegetated river embankment model for mid-flow condition under slope 1:1**

### 3.4.3 Analytical approach

The model study followed the Mohr-Coulomb failure criterion, where slope stability was assessed by calculating the factor of safety (FoS) using the Morgenstern-Price method. Each model scenario of both bare and vegetated slopes was analyzed in different hydraulic conditions mentioned in 3.4.1. By comparing FoS values, the mechanical improvement provided by *Hibiscus tiliaceus* roots was quantified for the selected slope angles and selected scenarios.

**Table 3 – Parameters applied in the model**

| Layer depth (m) | Description | Soil Cohesion (kPa) | Apparent cohesion due to roots (kPa) | Total cohesion (kPa) | Friction angle (degrees) | Bulk unit weight (kN/m³) | Dry unit weight (kN/m³) |
|---|---|---|---|---|---|---|---|
| 0 to 1.5 | Live stem | 5 | 16 | 21 | 25 | 17 | 13 |
| 1.5 to 2.25 | High root density | 5 | 16 | 21 | 25 | 17 | 13 |
| 2.25 to 2.75 | Mid root density | 5 | 10 | 15 | 25 | 17 | 13 |
| 2.75 to 3.25 | Mid-low root density | 5 | 5 | 10 | 25 | 17 | 13 |
| 3.25 to 4 | Low root density | 5 | 3 | 8 | 25 | 17 | 13 |
| 4 to 6 | Cohesive soil | 5 | - | 5 | 25 | 17 | 13 |
| 6 to 11 | Granular soil | - | - | - | 34 | 18 | 13 |
| 11 to 17 | Laterite/Residual soil | 50 | - | 50 | 36 | 18 | 14 |

## 4. Results and Discussion

The study assessed three slope geometries (1V:1H, 1V:1.5H, 1V:2H) under four hydraulic conditions: Low flow in the river, Mid flow in the river, Full flow in the river, and Rapid drawdown conditions. For each case, with and without *Hibiscus tiliaceus* embankments were compared, focusing on the factor of safety (FoS) and slip surface behaviour.

### 4.1 Factor of Safety (FoS) Results

A summary of the FoS values obtained from the model analysis for each scenario is presented in Table 4.

**Table 4 - Summary of FoS values**

| Slope | Flow Condition | FoS without trees | FoS with trees | FoS Increase (%) by tree roots |
|---|---|---|---|---|
| 1V:1H (45°) | Low flow | 1.34 | 1.69 | 26.61% |
| | Mid flow | 1.19 | 1.45 | 21.75% |
| | Full flow | 1.45 | 1.71 | 18.05% |
| | Rapid drawdown | 0.68 | 0.91 | 35.21% |
| 1V:1.5H (33.7°) | Low flow | 1.55 | 1.74 | 12.13% |
| | Mid flow | 1.43 | 1.75 | 22.14% |
| | Full flow | 1.74 | 2.14 | 23.16% |
| | Rapid drawdown | 0.86 | 1.19 | 38.18% |
| 1V:2H (26.6°) | Low flow | 1.82 | 2.08 | 14.58% |
| | Mid flow | 1.67 | 2.04 | 22.21% |
| | Full flow | 2.06 | 2.48 | 20.36% |
| | Rapid drawdown | 1.08 | 1.42 | 31.88% |

For all slopes considered, the addition of *Hibiscus tiliaceus* roots significantly improved slope stability in all scenarios. While the slope without trees dropped below the safe FoS threshold (1.2) under rapid drawdown conditions in all selected slopes and mid flow conditions in steep slope, vegetated conditions raised the FoS, providing critical stability greater than FoS = 1, except in the slope angle 45°. However, the vegetated condition could improve the FoS up to 0.91 in a rapid drawdown on a steep slope. The greatest improvements (more than 30%) were observed during rapid drawdown, where mechanical root reinforcement played a vital role in resisting the sudden hydraulic stresses. Even under full flow, the presence of vegetation improved FoS from 1.45 to 1.71 in the slope angle 45° and more than 20% in other slopes, reflecting a meaningful safety margin.

The moderate slope (1V:1.5H) maintained FoS values above 1.2 in most conditions, except during rapid drawdown, where the FoS of the slope without trees fell to 0.86. With *Hibiscus tiliaceus roots*, FoS in rapid drawdown condition was improved by over 30% up to 1.19. Even under lower-stress conditions like low flow, *Hibiscus tiliaceus* roots provided a 12.13% increment in moderate slopes (in slope of 33.7°). Notably, full flow conditions show a FoS improvement from 1.45 to 1.71 (in slope of 45°), 1.74 to 2.14 (in slope of 33.7°), and 2.06 to 2.48 (in slope of 26.6°), showing that *Hibiscus tiliaceus* root reinforcement offers meaningful stability gains even under maximum flow.

Even on the mild slopes (26.6°), which naturally maintained FoS above 1.2 in most cases, vegetation provided additional safety margins, particularly under rapid drawdown, where FoS improved from 1.08 to 1.42. Although the mild slope (26.6°) was inherently stable under low and mid flow, *Hibiscus tiliaceus* root reinforcement increased FoS by 14–22%, enhancing resilience. During full flow, the mild slope without trees achieved a strong FoS of 2.06, but vegetation pushed this further to 2.48, confirming the added benefit of *Hibiscus tiliaceus* even for already stable geometries.

### 4.2 Change of Slip Surface due to Vegetation

The analysis of the change of slip surface due to vegetation revealed distinct differences between vegetated and non-vegetated slopes, especially under varying hydraulic conditions. The addition of *Hibiscus tiliaceus* roots notably altered the geometry, depth, and location of the critical slip surfaces, resulting in enhanced slope stability and reduced failure risks. Figures 13 (a) to (f) depict the change of the slip surface due to the vegetation in the selected slope angles.

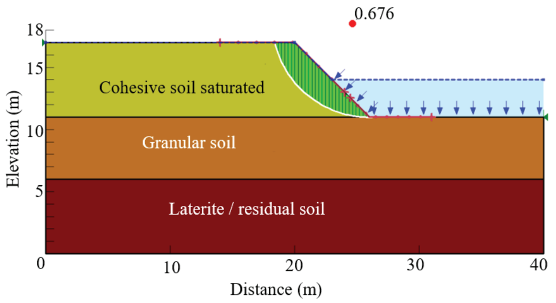


**Figure 13 (a) – Failure surface for 45° without trees**

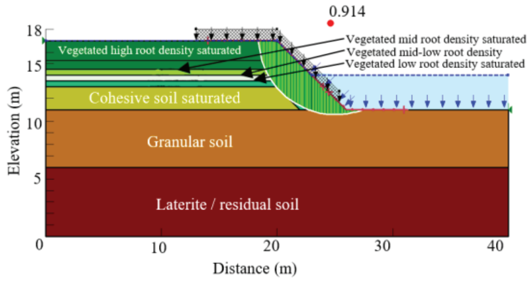


**Figure 13 (b) – Failure surface for 45⁰ with trees**

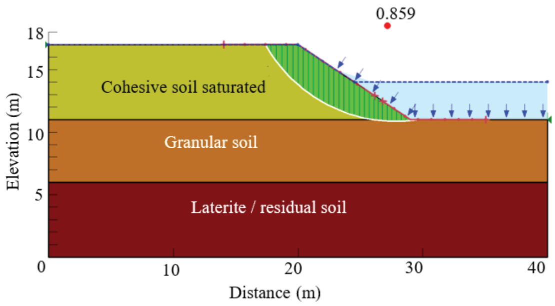


**Figure 13 (c) – Failure surface for 33.7⁰ without trees**

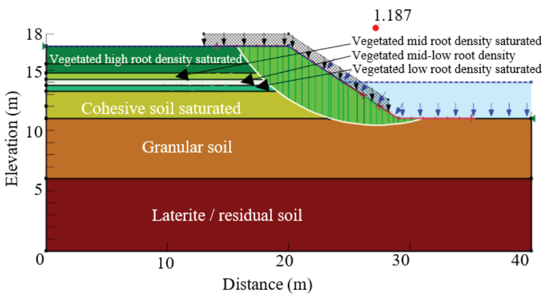


**Figure 13 (d) – Failure surface for 33.7⁰ with trees**

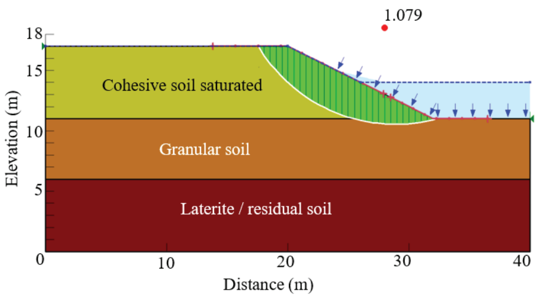


**Figure 13 (e) – Failure surface for 26.6⁰ without trees**

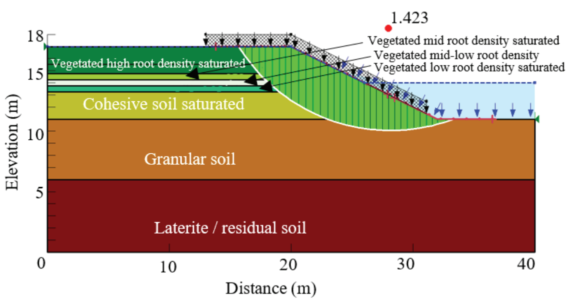


**Figure 13 (f) – Failure surface for 26.6⁰ with trees**

In the models without trees (Figures 13 (a), (c) & (d)), it displayed shallower slip surfaces. The upper zones confined the failure planes to the topmost 2.5 - 4 m of the slope, where the soft soil exists. Although this limits the extent and magnitude of potential slope failures, the presence of a failure surface within a soft soil layer still reduces slope stability.

In the vegetated slopes (Figures 13 (b), (d) & (f)), critical slip surfaces consistently developed as deeper rotational failures, particularly under rapid drawdown conditions. These failures typically extended below the shallow soft soil layer, engaging the zones within the granular soil layer. This behaviour reflects the vulnerability of slopes without trees when exposed to saturated or fluctuating pore pressures, particularly during rapid hydraulic transitions.

In addition to the improvements to the FoS, the presence of vegetation transformed the nature of potential slope failures, proving *Hibiscus tiliaceus* as an effective NbS for river bank protection.

## 5. Conclusions

This study comprehensively evaluated the enhancement of riverbank stability resulting from root reinforcement by *Hibiscus tiliaceus*, providing timely insights for riverbank protection along the Kelani River, Sri Lanka. Numerical modelling using SLOPE/W was employed to compare the stability of vegetated and non-vegetated slopes for three slope geometries (1V:1H, 1V:1.5H, and 1V:2H) under four hydraulic scenarios, including the critical rapid drawdown condition. The results demonstrated that root reinforcement by *Hibiscus tiliaceus* consistently improved the factor of safety, with increases ranging from 12% to 38%, depending on slope geometry and river water level. These improvements were most pronounced on steeper slopes and under rapid drawdown conditions, where bare slopes frequently fell below the minimum acceptable safety threshold.

In addition to improved numerical stability, the presence of *Hibiscus tiliaceus* altered the characteristics of potential failure mechanisms by shifting slip surfaces into deeper, more competent soil layers, thereby reducing the likelihood of shallow and surface-level failures. This mechanical reinforcement effect is consistent with previously published experimental results and theoretical models, supporting the validity and reliability of the adopted modelling parameters.

Overall, the findings confirm that *Hibiscus tiliaceus* offers a viable, sustainable, and cost-effective alternative to conventional structural measures for riverbank stabilization. Beyond enhancing mechanical resistance, it contributes to ecological resilience, reinforcing its suitability as a Nature-based Solution (NbS) for tropical river systems. Future research should focus on in situ field testing, long-term monitoring of live root systems, and integrated assessments of mechanical and hydrological interactions. By strengthening both local and global understanding, this study supports the development of practical, nature-based river management strategies aligned with sustainable development and climate adaptation objectives.

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