STRENGTHENING OF A SLOPE AT VARANDHA GHAT USING COMPOSITE MEASURES INCLUDING GEOSYNTHETICS: A NUMERICAL MODELING APPROACH WITH GEOSTUDIO

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ABSTRACT
This study evaluates an innovative composite stabilization system for landslide-prone Varandha Ghat (18.128987°N, 73.605047°E) in Maharashtra's Western Ghats. Combining geosynthetics, soil nails (8-10m), and gabion walls with GeoStudio modeling, the solution improved stability from critical (FoS=0.875) to safe levels (FoS=1.523). Laboratory tests on lateritic soils (c=17.18kPa, φ=28°) informed the design, which features geotextile-wrapped drains for pore pressure reduction and wire mesh for surface protection. The system offers 30-40% cost savings over conventional methods while effectively addressing both shallow erosion and deep-seated failures. These findings demonstrate a sustainable approach for monsoon-vulnerable slopes, with recommendations for real-time monitoring and bioengineering integration to enhance long-term resilience in similar terrains.

Keywords: Slope stability, geosynthetics, soil nailing, GeoStudio, Factor of Safety, Varandha Ghat.

I. INTRODUCTION
Varandha Ghat, a vital mountain pass in the Western Ghats of Maharashtra, frequently experiences landslides, especially during the monsoon. The region's steep slopes, fractured basalt geology, lateritic soils, and inadequate drainage systems contribute significantly to slope instability, posing risks to infrastructure, human life, and the environment. Traditional stabilization methods have proven insufficient for long-term resilience.

This study investigates the application of composite slope stabilization techniques including soil nailing, geo-mats, subsurface drainage, and gabion toe walls to improve slope safety. Using GeoStudio's SLOPE/W module, the research models slope behavior under current and treated conditions to evaluate changes in the Factor of Safety (FoS). The objective is to develop a sustainable, cost-effective solution tailored to the geotechnical and environmental challenges of Varandha Ghat.

II. Literature Review
Recent studies highlight the growing use of geocells and geosynthetics for sustainable slope stabilization. Song et al. (2023) demonstrated that geocell confinement combined with vegetation significantly reduces erosion and displacement under simulated monsoon conditions. Similarly, Ghani et al. (2024) and Thomson & Divya (2024) confirmed that geocells enhance load-bearing capacity and shear resistance in soft and lateritic soils, even under saturated conditions.

Field and numerical studies, such as those by the Indian Geotechnical Journal (2022) and IAEME (2021), emphasized the effectiveness of layered geosynthetic systems—integrating geotextiles and crushed aggregates—to improve settlement control and slope stability. Plastic waste-filled geocells (E3S, 2021) and soil-nail monitoring strategies (Vulcanhammer, 2017) also offer eco-friendly and instrumented solutions, respectively.

Internationally, Ma & Javankhoshdel (2024) stressed the need to assess geotextile interface strength in layered slopes, while Roy et al. (2024) provided insights into unsaturated slope behavior under seismic and loading conditions. Zhenyang et al. (2025) applied predictive models for earthquake-induced displacements, and Van Asch et al. (2007) offered a foundational review of physically based landslide models. Kumar et al. (2017) further modeled collapse mechanisms under varying moisture conditions, relevant to monsoon-induced failures.

These findings collectively support the integrated use of geocells, drainage systems, and vegetation in stabilizing complex slopes like those in Varandha Ghat, particularly when validated through advanced simulation tools such as GeoStudio.

III. SITE DESCRIPTION AND PROBLEM STATEMENT

Varandha Ghat, located in the Pune district of Maharashtra (18.1865° N, 73.6204° E), is a crucial mountain pass in the Western Ghats, linking Bhor to Mahad. Situated at an elevation of approximately 600 meters and stretching over 10–15 km, the ghat traverses rugged terrain near the Kundalika River. The area is geologically characterized by fractured Deccan Trap basalt overlaid with lateritic and weathered soils. Abundant in biodiversity and historical significance home to the Shivthar Ghal cave temple Varandha Ghat also features a narrow, winding road prone to monsoon damage. Frequent landslides, inadequate drainage, and anthropogenic pressures such as unregulated tourism and construction contribute to persistent slope instability, making it a high-priority site for stabilization efforts. Varandha Ghat, a crucial mountain pass in Maharashtra's Western Ghats, faces frequent landslides due to steep terrain, fractured basalt, lateritic soils, and poor drainage especially during the monsoon. Conventional stabilization methods have proven inadequate for long-term slope stability. This study proposes a composite stabilization approach combining soil nailing, geo-mats, wire mesh, geotextile-wrapped drainage systems, and gabion toe walls to reinforce both surface and subsurface slope conditions. The effectiveness of these measures is evaluated through field data and numerical modeling using GeoStudio (SLOPE/W), focusing on improvements in the Factor of Safety (FoS). This integrated method aims to offer a sustainable and resilient solution to recurring slope failures in the region.

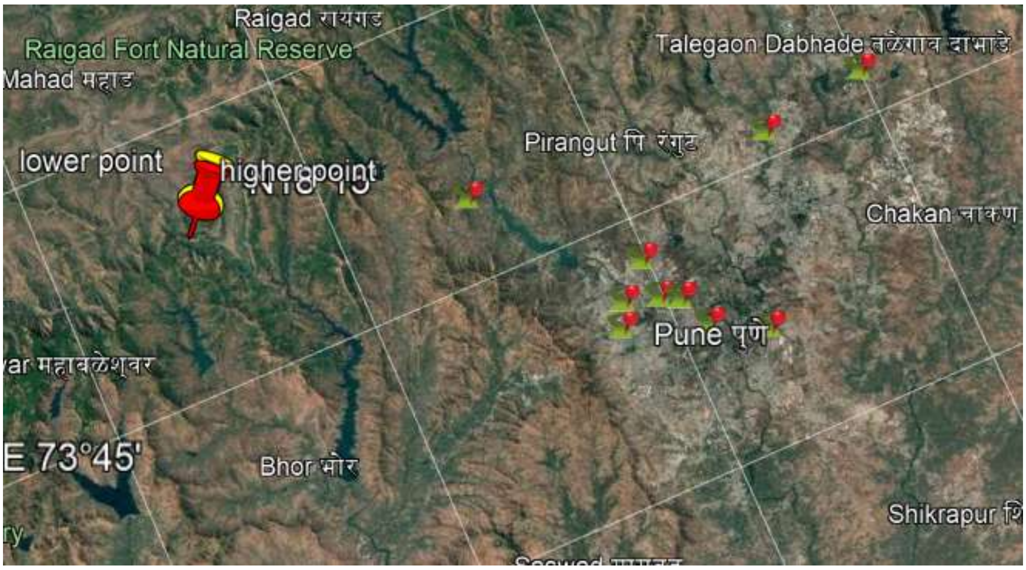
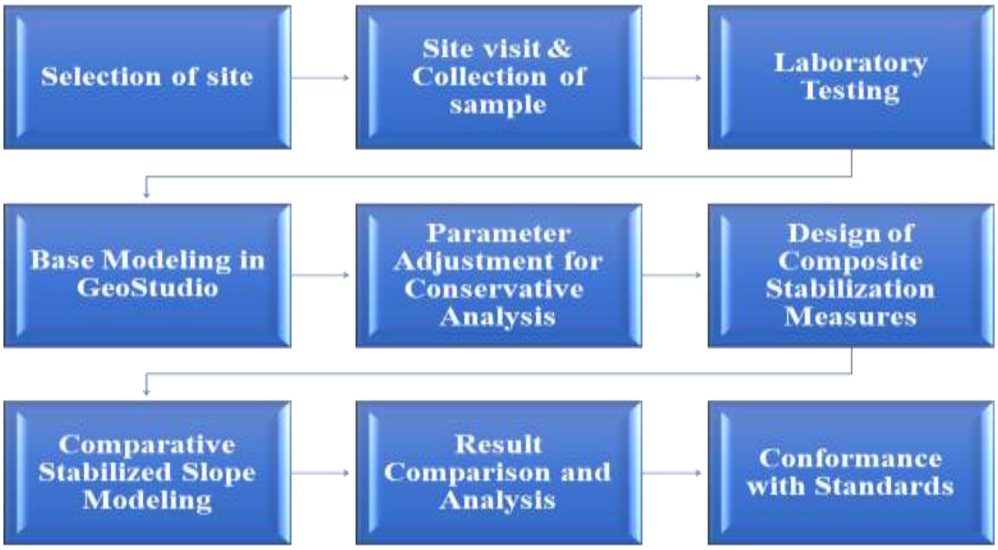


Fig.1(Location marking from Google Earth)

IV. AREA OF STUDY

The present study focuses on a landslide-prone section of Varandha Ghat along State Highway SH-97 in the Western Ghats of Maharashtra, India, connecting Bhor (Pune) to Mahad (Raigad). The selected site, located near a curved and vulnerable stretch (18.1865° N, 73.6204° E), lies at an elevation of 600–650 meters and features steep slopes ranging from 35° to 55°, underlain by weathered Deccan Trap basalt and lateritic soil. With annual rainfall averaging 3500–4000 mm and poor drainage infrastructure, the area experiences frequent slope failures during the monsoon (June–September). This location was selected based on its history of landslides (2017–2024), ease of access for monitoring, and its representation of typical distressed slopes in the Western Ghats. The study involves geotechnical assessment and slope stability modeling using GeoStudio (SLOPE/W), with proposed stabilization measures including soil nailing, geomats, geotextile-lined drainage, double twisted wire mesh, and a gabion toe wall.

V. METHODOLOGY



The study began with data collection from landslide-prone areas in Maharashtra, including Varandha Ghat, Taliye village, Adarwadi, and Dongarwadi, using news reports and geospatial coordinates. Field investigations revealed frequent landslides in Taliye, prompting soil sampling from Varandha Ghat for geotechnical testing. Laboratory analyses—including sieve analysis, Atterberg limits, specific gravity, Proctor compaction, CBR, direct shear, and permeability tests—provided essential soil parameters for stability assessment. Using GeoStudio's SLOPE/W, a base model of the natural slope yielded a Factor of Safety (FoS) of 0.875, confirming instability. A conservative cohesion value (55 kPa, adjusted from lab-measured 17.18 kPa) was adopted for realistic modeling.
Composite measures—including PVC drainage, gabion toe walls, and erosion control (geomats)—were integrated into the final design, demonstrating that soil nailing with benching optimally reinforces slopes, even under adverse conditions. The results underscore the effectiveness of combined mechanical and drainage solutions for landslide mitigation in the Western Ghats.

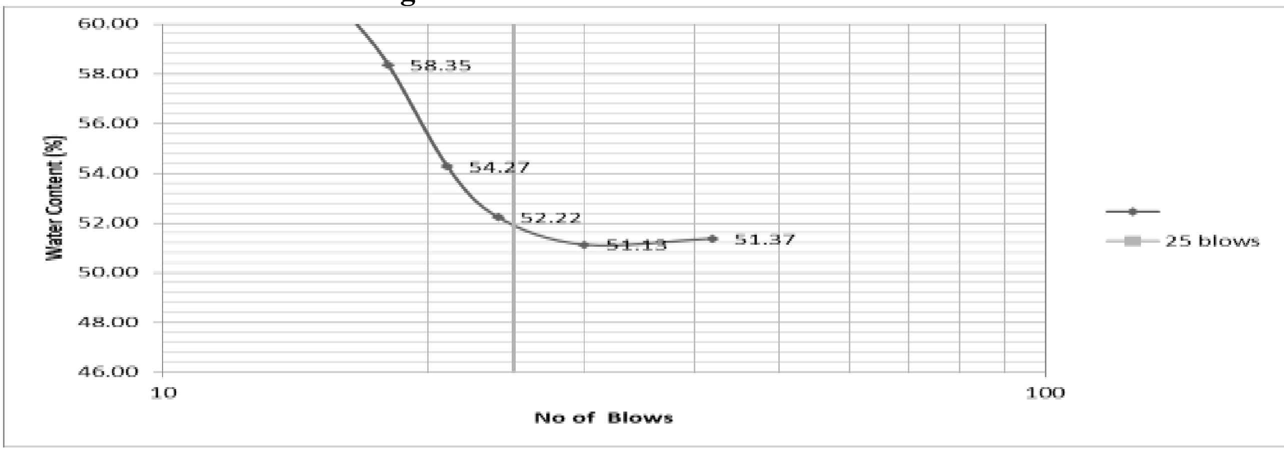
VI. RESULTS AND ANALYSIS

1. Laboratory test results:

Sr No	Test Performed	Parameters	Results
1	Standard Proctor Test	Water Content (%)	25
		Dry Density (gm/cc)	1.34
2	Atterbergs Limits Test	Liquid Limit (%)	52
		Plastic Limit (%)	44.06
		Plastic Index	7.94
3	Sieve Analysis	Soil Type	Sand
		Soil Classification	SP-SM
4	Specific Gravity		2.733

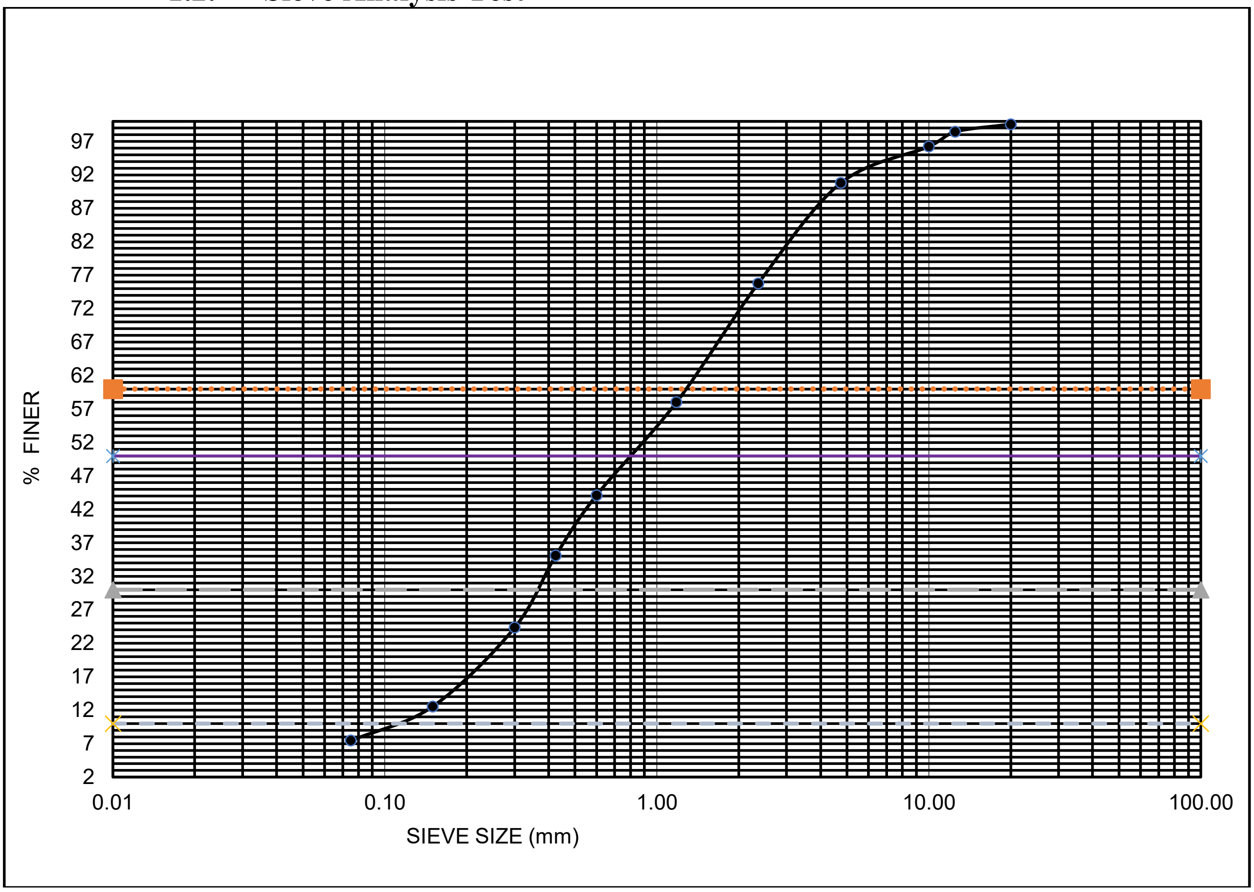
5	CBR (%)		13.5
6	Direct Shear test	Cohesion (Kpa)	17.8
		Friction Angle	39°
7	Permeablity	k	0.045
8	Unit weight (gm/cc)	1.718	17.18KN/m^3

1.1. Atterbergs Limits Test



Graph no. 1 (Atterbergs Limits Test)

1.2. Sieve Analysis Test



Graph no. 2 (Sieve Analysis Test)

2. Base Modeling in GeoStudio

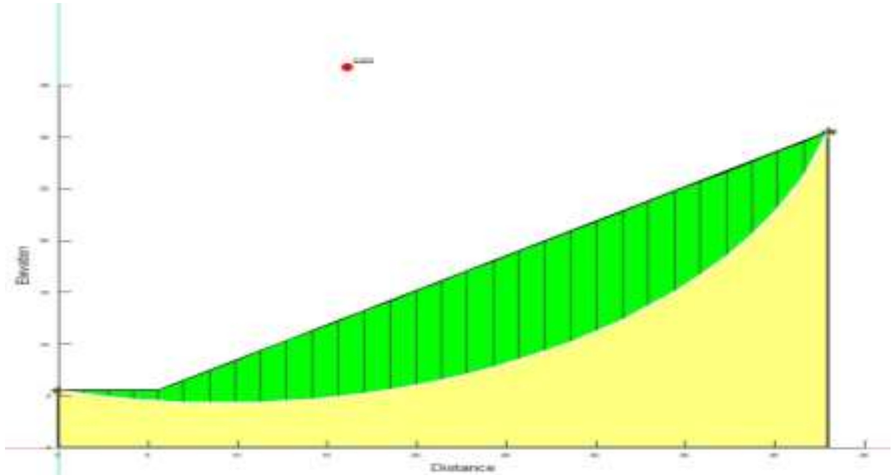


Fig.2 (Base Slope Analysis model)

The slope was found to be critically unstable. This model reflected the existing site condition and validated the need for immediate stabilization intervention.

3. Comparative Stabilized Slope Modeling

3.1. Model 1: Benching + $\gamma = 18$ kN/m³

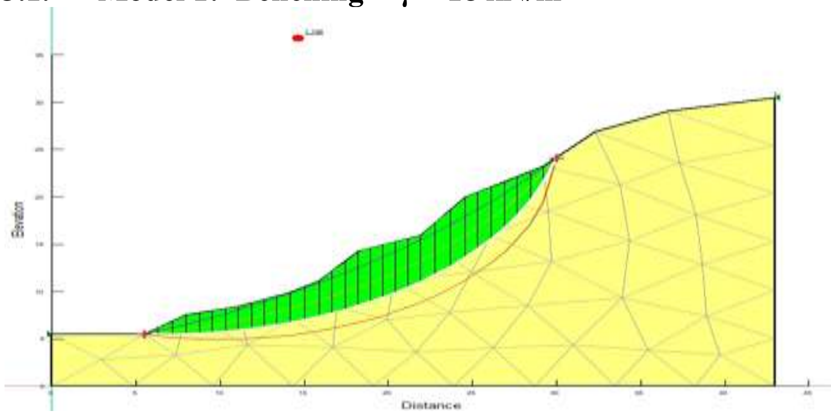


Fig.3(Slope Analysis model without using composite measures)

A benched slope with a bulk unit weight of 18 kN/m³, reflecting compacted fill conditions. Obtained FoS=1.196.

3.2. Model 2: Benching + Soil Nailing + $\gamma = 18$ kN/m³

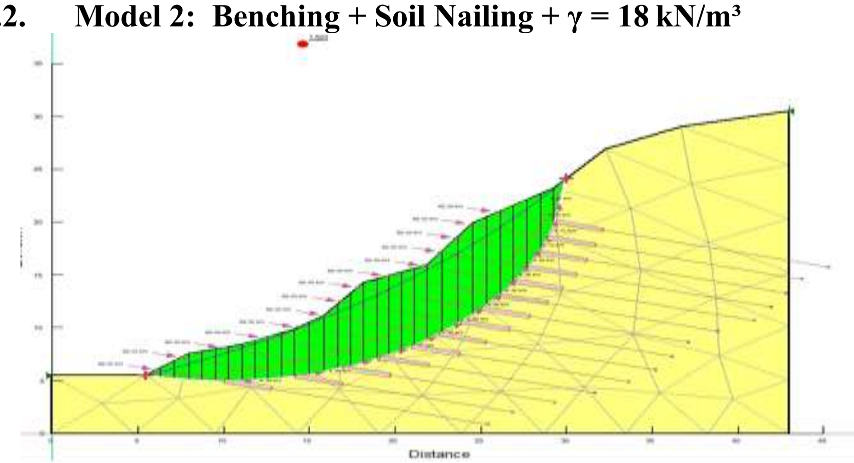


Fig.4 (Slope Analysis model with using composite measures)

Same as Model 1, but with the addition of soil nails for internal reinforcement, improving shear resistance. Obtained FoS=1.52.

3.3. Model 3: Benching + $\gamma = 20$ kN/m³

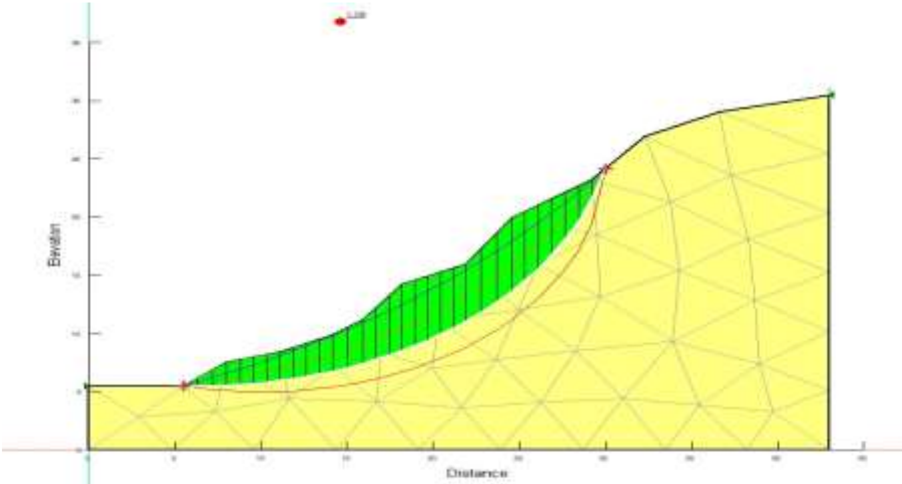


Fig.5(Slope Analysis model without using composite measures)

This model simulates higher moisture conditions or denser soil, increasing the bulk unit weight to 20 kN/m³. Obtained FoS=1.138

3.4. Model 4: Benching + Soil Nailing + $\gamma = 20$ kN/m³

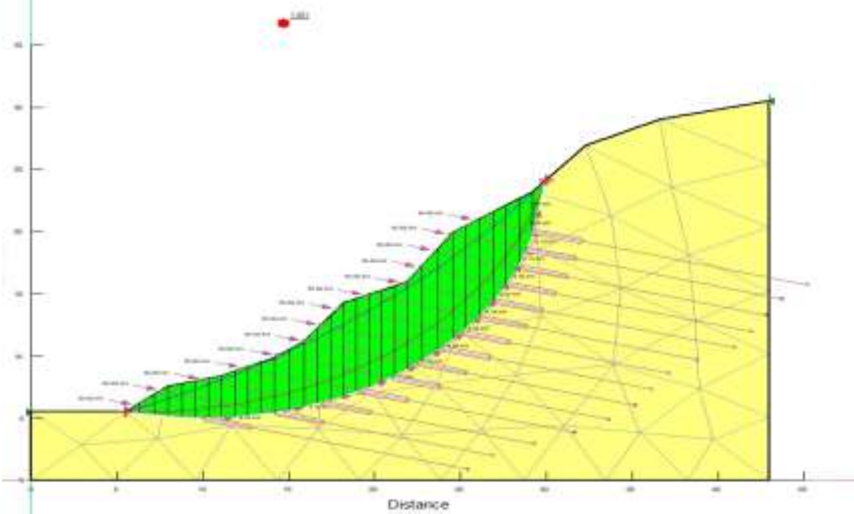


Fig.6(Slope Analysis model with using composite measures)

The most reinforced model, incorporating both increased unit weight and soil nails for maximum stability under adverse conditions. Obtained FoS=1.451.

VII. FUTURE SCOPE OF STUDY

To enhance slope stability assessments, future research should incorporate in-situ testing (shear tests, pressure meter tests) and real-time monitoring (inclinometers, piezometers) for accurate parameter determination. Long-term performance evaluation over multiple monsoons is needed to assess durability. Bioengineering approaches, such as integrating vegetation with geosynthetics, could improve ecological sustainability. Advanced 3D numerical modeling (PLAXIS 3D, FLAC 3D) and smart geosynthetics with embedded sensors may provide deeper insights into slope behavior under dynamic conditions. Additionally, environmental impact assessments and scalability studies should be conducted to ensure sustainable and adaptable solutions for other landslide-prone regions. These findings could inform policy guidelines for slope stabilization in vulnerable areas.

VIII. CONCLUSION

This study developed an integrated slope stabilization system for landslide-prone Varandha Ghat in Maharashtra's Western Ghats, combining geosynthetics, soil nailing, drainage systems, and gabion

structures. Through comprehensive field investigations, laboratory analyses, and GeoStudio modeling, researchers found conventional stabilization methods inadequate for the region's lateritic soils under heavy monsoon rainfall.
The natural slope showed critical instability (FoS=0.875), while the proposed composite system achieved safe stability levels (FoS>1.4) through synergistic application of benching, soil nails (FoS=1.523), geotextile drainage, and gabion walls. The solution effectively addressed both surface erosion and deep-seated failures, validated through parametric modeling with adjusted cohesion parameters (55 kPa) matching field conditions. The study recommends urgent implementation by infrastructure authorities, installation of monitoring instrumentation, and further research into bioengineering combinations. Findings demonstrate a viable, sustainable approach for landslide mitigation that could be adapted to similar geologically vulnerable regions across India.

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