

INVESTIGATION OF NATURE-INSPIRED SOLUTIONS FOR PROTECTING UNSTABLE SLOPES

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Slope instability is a critical issue in geotechnical engineering, causing landslides, erosion, and loss of infrastructure worldwide. Conventional stabilisation techniques, such as retaining structures, soil nailing, and earth anchors, are effective but involve high costs, heavy resource use, and environmental impacts. They are often unsustainable under changing climatic conditions. This has led to the search for alternative techniques that are environmentally friendly, cost-effective, and scalable.

Nature-inspired solutions (NIS) offer a promising approach by mimicking the structural and functional strategies of natural systems. This study draws inspiration from tree root biomechanics, where branching networks stabilise slopes by anchoring the soil and improving shear strength. The aim was to investigate the potential of a synthetic root-inspired anchoring system for slope stabilisation through laboratory testing.

Anchors were fabricated using pre-drilled PVC pipes into which cement grout was pressure-injected, creating branch-like extensions extending into the soil mass. Models were tested under controlled conditions to examine the effect of soil type, moisture content, curing time, and branch configuration. Three soil types were examined; medium sand, coarse sand with silt, and fine gravel with clay, representing cohesionless, mixed, and cohesive-frictional conditions. Moisture content varied between 1% and 5%, curing time ranged from 3 to 28 days, and anchors with different branch numbers (0–8) were tested. Incremental loading using a pulley system was applied until failure, and pull-out capacity was recorded.

Results highlighted the following key findings. Moisture content strongly influenced performance, with pull-out capacity increasing up to an optimum of about 4%, after which excess moisture reduced resistance by weakening soil cohesion. Curing time enhanced anchorage strength, with maximum capacity at 28 days, emphasising the importance of grout strength development and soil–anchor bonding. Branch geometry was another critical factor: capacity increased consistently with higher branch counts, confirming that branching improves interlocking and distributes loads effectively. Soil type also played a major role. Fine gravel with clay achieved the highest pull-out resistance (131.8 N), followed by coarse sand with silt (106.4 N) and medium sand (80.8 N), due to combined particle interlocking and clay-induced cohesion, which improved the grout–soil bond.

Overall, the research supports that root-inspired synthetic anchors can significantly improve pull-out performance under laboratory conditions and offer an environmentally friendly, cost-effective, and time-saving alternative to conventional stabilisation techniques. While this study was limited to small-scale experiments, it establishes a strong foundation for future work. Field-scale testing, numerical modelling, and optimised anchor design should be pursued to advance practical applications. By applying biomimetic concepts to geotechnical engineering, this study supports the development of greener, more sustainable, and cost-effective solutions for slope stabilisation in landslide-prone zones.

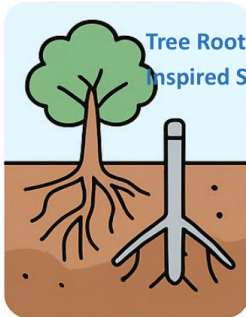
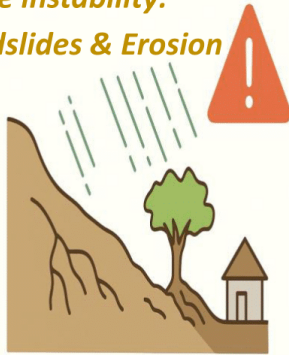
Keywords: Bio-inspired anchor, Pullout capacity, Pressure grouting, Slope stability, Tree root biomechanics

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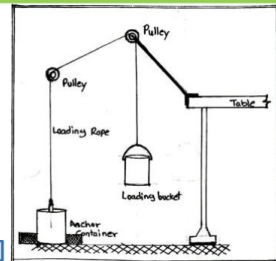
Investigation of Nature-Inspired Solutions for Protecting Unstable Slopes

Slope instability:

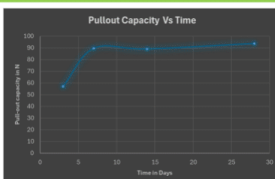
Landslides & Erosion



**Tree Root Biomechanics
Inspired Synthetic Anchor**

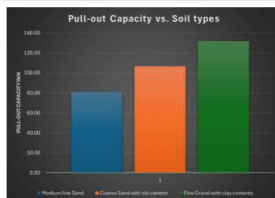
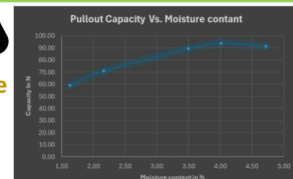


- Moisture content [1%-5%]
- Curing Time [3-28 days]
- Branch count [08]
- Various soil



**Maximum Capacity
at 28 days**

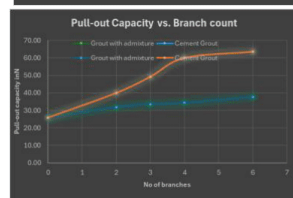
**Optimum Moisture
content 4%**



**Fine gravel with clay achieved
largest capacity 131.8 kN**



**Increasing with
branch Count**



Laboratory-scale tests confirmed that root-inspired synthetic anchors significantly improve pull-out resistance with optimal moisture, curing, branching, and soil conditions. They provide a sustainable, cost-effective, and time-saving alternative to conventional methods. Field-scale validation and numerical modelling are recommended for practical application.

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