Rainfall-Induced Herbaceous Vegetated Slope Instability and Risk Assessment

Amid intensifying global climate change, the escalating frequency and intensity of extreme rainfall events have led to a marked increase in slope instabilities. These hazards—ranging from surface erosion to shallow landslides—trigger cascading impacts for both human communities and natural ecosystems. A series of disasters triggered by intense rainfall events across various regions of the world revealed fundamental deficiencies in conventional slope stabilization approaches under escalating climatic extremes. As a result, the global engineering community now faces the critical challenge of balancing structural safety with ecological preservation in slope protection strategies, making this dual objective a cornerstone of modern disaster risk reduction frameworks.

Traditional slope stabilization methods, like concrete revetments and retaining walls, focus on providing rapid mechanical stability but cause significant ecological damage. These “strength-first” approaches degrade vegetation and soil structure, reduce biodiversity, fragment landscapes, and weaken natural recovery processes. In contrast, vegetation-based slope protection—a nature-based solution —offers a sustainable alternative. Plant roots enhance soil shear strength through mechanical reinforcement, while transpiration dynamically regulates soil moisture, creating a self-adjusting hydro-mechanical stabilization system. Such eco-engineering aligns with recommendations from the Intergovernmental Panel on Climate Change (IPCC), combining cost-effectiveness, carbon sequestration, and ecosystem restoration. However, despite its potential, the science underpinning herbaceous vegetation—a key player in rapid slope stabilization—remains underdeveloped compared to woody plants, leaving a critical gap in climate-resilient slope management.

The project aims at shedding light on enhancement of slope stability caused by the presence of herbaceous vegetation through three synergistic innovations: **(1) Mechanistic Insights**: Multiscale experiments will uncover how herbaceous roots stabilize soil across microscopic to macroscopic scales, bridging the gap between root-soil interactions and slope-wide instability; **(2) Advanced Numerical Modelling:** A new advanced model will incorporate the effects of root reinforcement and evapotranspiration on slope stability; **(3) AI-Driven Risk Prediction:** Machine learning algorithms, based on regional vegetation and climate data, will create dynamic risk assessment tools tailored to herbaceous slopes, helping develop customized protection strategies.

Since climate change renders old rainfall patterns unreliable, the existence of knowledge gaps in climate-adaptive slope management poses a risk to both infrastructure and ecosystem health. The project bridges ecological principles with cutting-edge geotechnical innovation, proposing a transformative approach that unifies multiscale root biomechanics, advanced numerical modelling, and AI-powered risk prediction. By decoding herbaceous root reinforcement mechanisms, redefining the instability criterion, and delivering a dynamic risk assessment framework, the project aims to pioneer **proactive, climate-adaptive slope management**—safeguarding lives, preserving ecosystems, and advancing global carbon neutrality goals.