Mitigating Debris Flows: The Role of In-Channel Forests

Xi'an Wang[1*], Jiangang Chen[2], and Han Bao[1]

[1]School of Highway, Chang'an University, Xi'an, China
[2]Key Laboratory of Natural Hazards and Engineering Safety, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, China

(*[*]Corresponding E-mail: wangxian@chd.edu.cn*)

Abstract: Although channel forests are recognized for their potential to mitigate debris flows, their effectiveness in trapping sediment remains inadequately quantified. This research examines, through physical modeling, how the trunk volume fraction—defined as the ratio of total trunk cross-sectional area to forested area, varying between 0.9×10^{-3} and 88.6×10^{-3}—affects deposition behavior and impact dynamics of debris flows. When debris flow enters the forested channel, a sharp rise in the energy slope of flow resistance initially disrupts the balance with the channel bed slope. This leads to reduced flow velocity, increased flow depth, and a subsequent decline in the energy slope. Concurrently, substantial sediment deposition occurs within the forested segment, raising the bed slope until a new equilibrium is established with the energy slope. The attenuation rate of the peak impact force was measured between 15.8% and 79.0%, while sediment retention rates varied from 3.0% to 31.7%. The attenuation of peak impact force correlated most strongly with relative opening, whereas sediment retention was most closely associated with the initial resistance energy slope of the forest. Viscous debris flows showed a moderately lower peak force attenuation compared to diluted flows, but higher sediment retention. Sediment deposition increased the bed slope by 0.002 to 0.089, a change proportional to the initial resistance energy slope, with proportionality coefficients of 2.3% for viscous and 3.4% for diluted debris flows. Additionally, this study proposes new methodologies for estimating deposition slope and potential sediment retention volume in wooded channels. For more details on this study, please refer to Wang et al. (2025).

Keywords: ***Debris flow, Wooded channels, Sediment trapping, Deposition slope, Impact force.***

Introduction

Forests on both channels and slopes play a vital role in mitigating debris flows (Cui and Lin, 2013). In contrast to the flow interception and sediment reduction effects of forests on slopes (Imaizumi et al., 2008; Liu et al., 2023), the impact of forests within channels remains relatively unexplored. Some field cases provide valuable but incomplete quantitative data on the role of in-channel forests in regulating debris flows. (Ishikawa et al., 2003; Malik et al., 2013; Michelini et al., 2017). highlighting the urgent need for physical modeling experiments to investigate and understand the complete processes and mechanisms involved.

Methodology

The study focused on the regulatory effect of tree trunks on debris flow, with branches and leaves considered secondary (Figure 1). Key parameters—flow depth, impact force, and deposition volume—were measured. Experiments were conducted in a 0.4 m-wide debris flow flume (Figure 2); detailed procedures are in Wang et al. (2025).

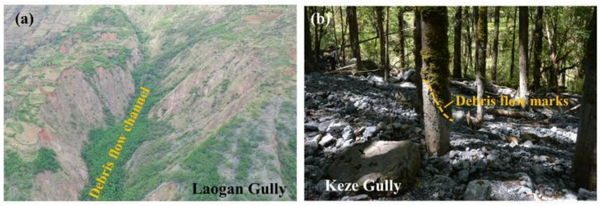

Figure 1, The forests growing in debris flow channels.

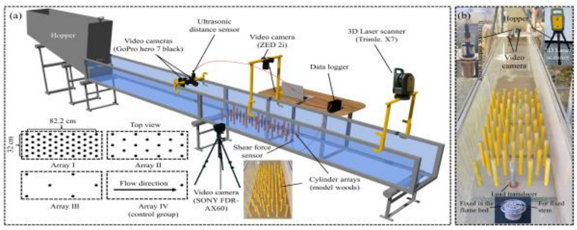

Figure 2, Experimental setup.

Results and Discussion

In Figure 3a, the debris flow process through the wooded channel is illustrated using D1_L8_C0.5 as an example, while Figure 3b provides a schematic diagram of this process. The passage of debris flow through wooded areas can be conceptualized as a complex interplay between the energy slope of the debris flow and the slope of the channel bed, as illustrated in Figure 3c. Upon entry into channel woods, debris flow experienced a reduction in velocity and an increase in depth, eventually adapting to the new resistance environment and a substantial volume of sediment was trapped in the wooded channel. Deposition depth decreased progressively from upstream to downstream in wooded channels, thereby elevating the slope of the wooded channel bed.

Both the attenuation rate of peak impact force in the downstream end of woods (A_F) and the sediment retention rate (A_S) exhibited negative correlations with the relative opening (R_o), positive correlations with the initial resistance energy slope of woods (ΔS_e) and tree trunk volume fraction (ϕ). Specifically, A_F demonstrated the strongest correlation with R_o, whereas A_S was most strongly correlated with ΔS_e (Figure 4). Viscous debris flows exhibited slightly lower A_F than diluted debris flows, with the reverse being true for A_S. In the experiments, the A_F ranged from 15.8% to 79.0%, while the A_S fell between 3.0% and 31.7%.

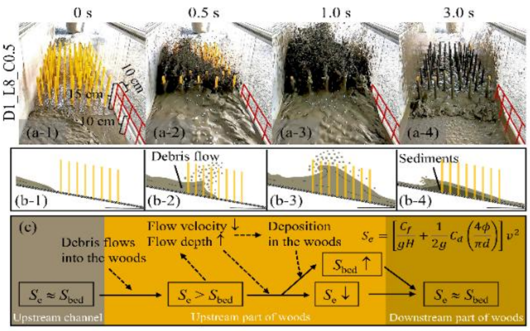

Figure 3, The regulation mechanism of woods on debris flow (D1_L8_C0.5).

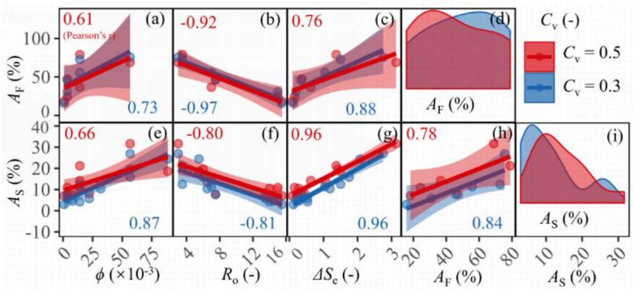

Figure 4, The effects of, R_o, and ΔS_e on A_F and A_S.

The bed slope increment(ΔS_{bed}) caused by deposition in wooded channel showed negative correlations with R_o and positive correlations with ΔS_e and ϕ, with the strongest correlation observed with ΔS_e. ΔS_{bed} was directly proportional to ΔS_e, accounting for approximately 2.3% and 3.4% of ΔS_e for viscous and diluted debris flows, respectively (Figure 5).

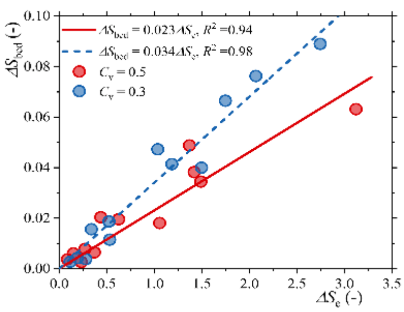

Figure 5, The relationship between ΔS_{bed} and ΔS_e.

A novel method was developed to calculate deposition slope and potential sediment retention in wooded channels. Results show that increasing both stand density and tree breast diameter reduces the peak impact force of debris flow and enhances sediment trapping. However, natural forests undergo thinning as trees grow, leading to decreased stand density. Field data from China, Europe, and Japan indicate that the maximum ϕ value in natural forests is about 14×10^{-3} (Figure 6). When ϕ < 14‰, the maximum A_F and A_S values were about 61.0% and 14.8%, respectively, with a maximum ΔS_{bed} of approximately 0.039.

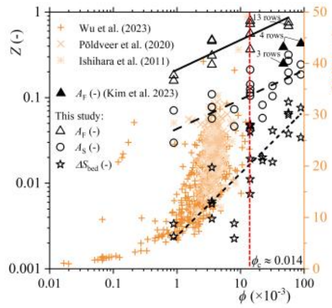

Figure 6, The tree trunks volume fraction of natural woods and its regulation capacity on debris flow.

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