# Jammed and Mobilized Domains in Debris Flow, Debris Avalanche and Rock Avalanche against Slit-check Dams

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# Jammed and Mobilized Domains in Debris Flow, Debris Avalanche and Rock Avalanche against Slit-check Dams

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SUMMARY: Multiphase geophysical flows impacting slit-check dams can create jammed and mobilized domains, which partially govern the overspreading, energy-breaking, and trapping dynamics. This study presents systematic numerical simulations of debris flows, debris avalanches, and rock avalanches against single-slit structures with narrow, medium, and broad openings, using the coupled computational fluid dynamics and discrete element method (CFD-DEM). A typical debris flow is treated as a mixture of discrete particles (by DEM) and a continuous slurry (by CFD). This model well captures essential physics observed in experiments. We show how flow materials, dynamics, and barrier filters alter the impact-induced jammed and mobilized domains that possibly affect the energy-breaking efficiency. Our results reveal that flow materials (wet versus dry) and dynamics (slow versus fast) jointly drive the hazardous overspreading dynamics, while slit openings dominate the trapping patterns, including clogging with domes, blockage, and self-cleaning.

**Keywords**: slit-check dam, debris flow, debris avalanche, rock avalanche, CFD-DEM

## 1 Introduction

Slit-check dams are widely used countermeasures against multiphase geophysical flows (Hungr et al., 1984). These structures can trap part of the debris and diminish the peaks of downstream solid discharge and impact energy. However, the complex impinging flow characteristics (e.g. solid-liquid nature, wide ranges of Froude-number and particle size distributions) and simultaneous multiple processes (e.g. flow reduction and separation, debris jamming, filtering, and overtopping) limit rational studies to simplified models (Piton et al., 2022). Also, owing to this complexity, the design of the most suitable structure is, however, problematic.

Existing studies on the impact behavior of geophysical flows against slit-check dams mainly rely on theoretical, small-scale physical, and numerical analysis. However, the aforementioned complexity also goes beyond the limits of the validity of hydraulic formulas (Armanini & Larcher, 2001) or theoretical predictions (Piton et al., 2022). Moreover, the majority of physical studies focused on the hydraulic conditions or lack quantitative indices for evaluating the trapping, overspreading and energy-breaking efficiencies (Armanini & Larcher, 2001; Rossi & Armanini, 2019). Alternatively, numerical studies enable detailed investigations of mechanical trapping and energy dissipations, however, mainly based on discrete element modeling with monodisperse flows (Leonardi et al., 2019; Marchelli et al., 2020). In practice, slit dams are commonly installed in low-gradient channels, whilst most physical and numerical studies adopted high-gradient flumes, which may produce different impact behavior from reality.

In this study, we employ a coupled computational fluid dynamics and discrete element method (CFD-DEM) to simulate impacts of debris flows, debris avalanches, and rock avalanches (Fig.

1c) on single-slit dams with narrow, medium and broad openings (Fig. 1b). We aim at quantitatively examining the impact-induced jammed and mobilized domains to advance our knowledge of the overspreading, energy-breaking, and trapping mechanisms.

## 2 Method and Model Setup

The CFD-DEM modeling of multiphase geophysical flows and their impacts on different resisting structures are developed and validated in previous works (Zhao & Shan, 2013; Kong et al., 2021a, 2022a, 2023). The motions of solid particles are governed by Newton's equations, and the fluid is controlled by the locally-averaged Navier-Stokes equation for each fluid cell. Specifically, free surfaces are simulated by the Volume-of-Fluid (VOF) method implemented in CFD. Four fluid-solid interaction forces, including drag, buoyancy, viscous, and virtual mass forces, are exchanged between CFD and DEM computations. Details of the governing equations and two-way coupling schemes can be found in Zhao & Shan (2013).

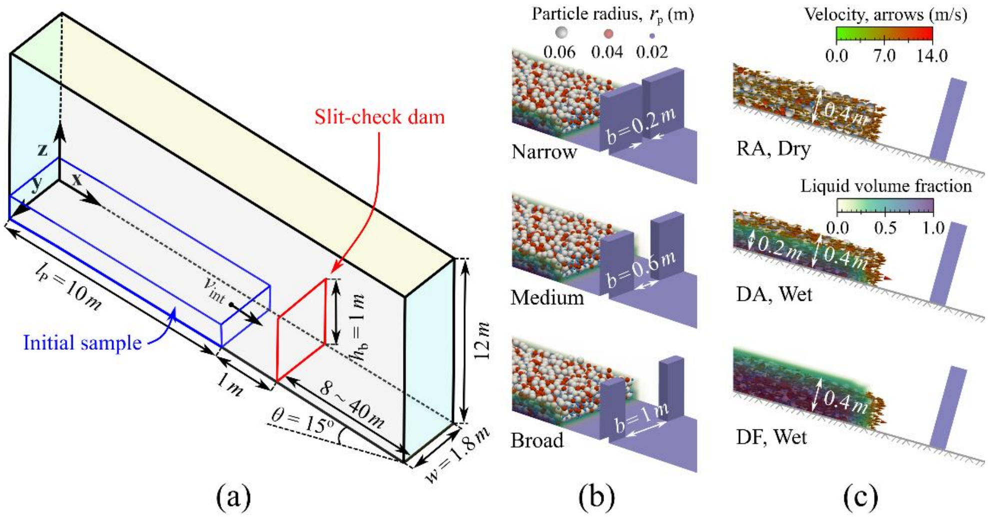


Fig. 1 (a) Model geometry prior to the release of the initial sample. (b) Oblique views of slit-check dams with slit width $b$ equal to 0.2 m, 0.6 m, and 1 m. (c) Side views of representative cases of debris flow, debris avalanche, and rock avalanche impacting a slit-check barrier at the frontal impact process.

Tab. 1 Test program

| **Test groups** | **Initial velocity**, $v_{int}$ [m/s] | | | **Pre-impact** Fr |
|---|---|---|---|---|
| | **Narrow (N)** | **Medium (M)** | **Broad (B)** | |
| Debris Flow (DF) | 1,2,4,6,8,10,12 | 1,2,4,6,8,12 | 1,2,4,6,8,12 | 0.8 ~ 6.4 |
| Debris Avalanche (DA) | 1,2,4,6,8,12 | 1,2,4,6,8,12 | 1,2,4,6,8,12 | 0.6 ~ 6.3 |
| Rock Avalanche (RA) | 2,4,6,8,12 | 2,4,6,8,12 | 2,4,6,8,12 | 0.9 ~ 6.1 |

Fig. 1a illustrates the model setup for Rock Avalanches (RA), Debris Avalanches (DA), and Debris Flows (DF) against single-slit check dams with different openings, constructed on a low-gradient slope with $\theta$ = 15°. The initial heights of viscous slurries in RA, DA, and DF cases (Fig. 1c) are set to 0 m, 0.2 m and 0.4 m, respectively. The sample will be uniformly assigned with prescribed initial velocities ($v_{\text{int}}$ = 1 ~ 12 m/s) and released to impact the dam. Consequently, a broad range of Fr (0.6 ~ 6.4) is produced with a constant pre-impact flow depth of ~ 0.4 m. At the initial state, only fluid cells in the mixture sample are filled with liquid, leaving the rest of the CFD domain filled with air. The interstitial liquid in a typical debris flow/avalanche is described by a Herschel-Bulkley model with shear-thinning rheology (Iverson, 1997; Kong et al., 2022b). In DEM, the sides and bottom of the flow channel as well as the slit-check dam are modeled as fixed, rigid, and frictional walls. In particular, the single-slit dams have narrow, medium, and broad spacings with different lengths, i.e., $b$ = 0.2 m, 0.6 m, and 1 m (Fig. 1b), producing various transverse blockages $b/w$ and relative spacings $b/\delta$, where $\delta$ is the maximum particle diameter. The test scenarios are summarized in Table 1.

## 3 Results and Discussion

Fig. 2 compares the jammed and mobilized domains of representative wet and dry cases against slit dams with different openings, showing distinct features in flow redirection, separation, filtering, and overtopping. The dead zone coexists with a flowing layer (see side view in Fig. 2c-middle). Moreover, wet flows produce much smaller jammed regions and larger mobilized domains than dry flows under Froude similarity. It is mainly due to dry flows undergoing a higher energy-sinking efficiency during the interactions than wet flows. Specifically, grain shear stress is considered more effective in energy dissipation than fluid viscous shearing, meanwhile, the fluid can dampen particle collisions and decrease interparticle friction.

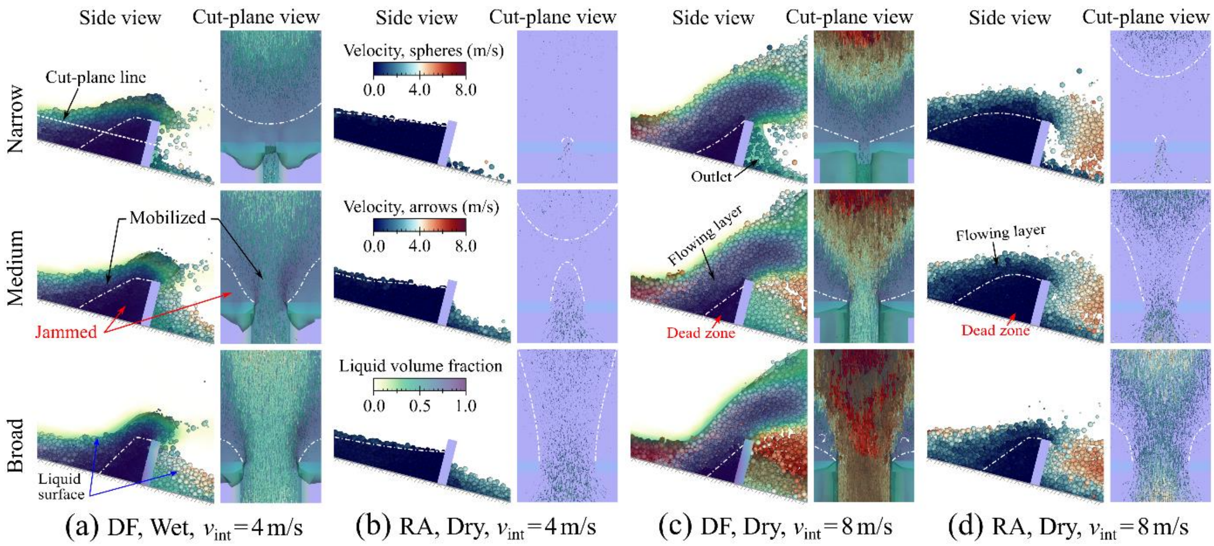


Fig. 2 Comparison of the jammed and mobilized domains of (a & c) debris flows and (b & d) rock avalanches impacting slit-check dams with narrow, medium, and broad slits with $v_{int}$ = 4 m/s and 8 m/s at $t$ = 1 s.

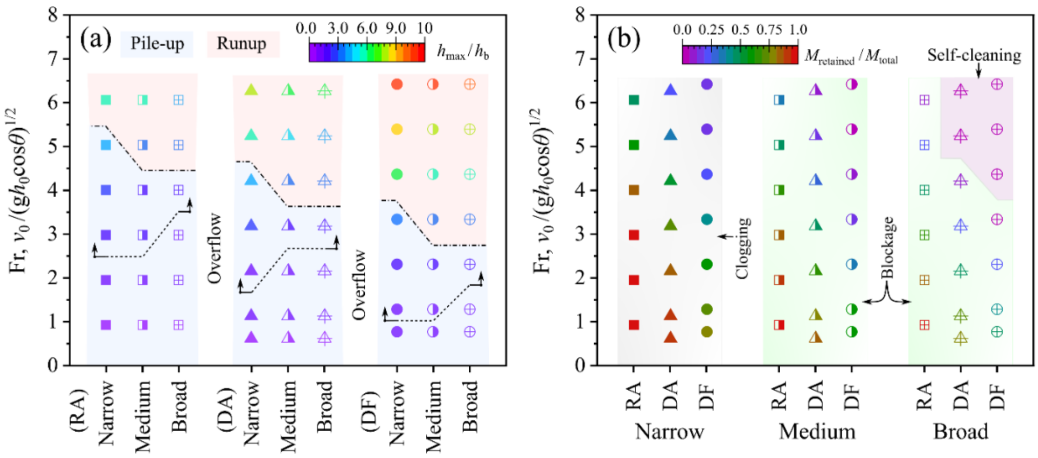


Fig. 3 Diagrams of (a) overspreading and (b) trapping dynamics for geophysical flows against slit-check dams.

Fig. 3a shows the normalized overspreading heights $h_{max}/h_b$ (color of symbols) and impact regimes (pile-up and runup, Kong et al., 2021b). DF cases produce the largest $h_{max}/h_b$ under

Froude similarity while RA cases undergo the smallest one under Froude similarity. This implies that flow materials and dynamics drive the hazardous overspreading. Fig. 3b presents the trapping efficiency $M_{\mathrm{retained}}/M_{\mathrm{total}}$ (color of symbols) and trapping patterns (i.e. clogging, blockage, and self-cleaning). Clogging is featured with domes (3D) or arches (2D), whilst no domes or arches are observed in blockage. The 'self-cleaning' denotes no retained particles in dam filters (Goodwin & Choi, 2020). These trapping patterns are controlled by the sizes of dam filters or openings.

## 4 Conclusion

We present systematic solid-liquid simulations of geophysical flows of variable natures against slit-check dams. Our results and findings help to advance the understanding of impact-induced jammed and mobilized domains, energy-breaking efficiency, overspreading dynamics, and trapping mechanisms, which are key concerns of slit structures.

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# Fw: 3rd JTC1 Workshop. Abstract review decision

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**From:** JTC12023 <jtc12023@ngi.no>
**Sent:** 30 November 2022 16:05
**To:** Mingfu Guan
**Cc:** Laura Rødvand
**Subject:** 3rd JTC1 Workshop. Abstract review decision

Dear author,
We pleased to inform you that the scientific committee has **accepted** your abstract, *Jammed and Mobilized Domains in Debris Flow, Debris Avalanche and Rock Avalanche against Slit-check Dams*, for an **oral presentation** at the " 3$^{rd}$ JTC1 workshop - Impact of global changes on landslides hazard and risk ". The workshop will be held 7-10$^{th}$ June in Oslo, Norway.

If you choose to resubmit your abstract, please include a list of changes against each point which is being raised when you submit the revised abstract. The deadline for revised abstracts is 10$^{th}$ February 2023. Revised abstracts shall be submitted to jtc12023@ngi.no.

The workshop will open for registration early 2023 at the workshop website: https://jtc1-2023.com/dates-and-registration/
We ask you kindly to notify us immediately if you do not plan to attend the workshop or present your abstract. Attendance of at least one author is required for inclusion in the workshop.

We look forward to seeing you in Norway in June.

On behalf of the Scientific Committee of 3rd JTC1 Workshop,

NGI Sincerely yours,
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