Multiple debris-resisting barriers with basal clearance: a study on impact force

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Abstract. Multiple barriers are advantageous on retaining large volumes of debris avalanches and debris flows compared with a single barrier because they can progressively arrest the flow and minimise the flow acceleration by facilitating the energy dissipation, thereby reducing barrier sizes. For closed-type multiple barriers [1], even flow with a small volume can be resisted by upstream barriers, resulting in an increase of maintenance work or a decrease of total retention capacity for next flow event. To optimise the design of multiple barriers, basal clearance [2–4] is usually constructed beneath the barriers to allow for discharge of flow (Fig. 1). Moreover, a basal clearance also serves to reduce the impact forces on barriers [5]. Despite the value of basal clearance, the design remains empirical.

In this study, impact dynamics of debris flow against multiple barriers have been investigated by conducting laboratory-scale flume model tests. The debris flows and multiple barriers were simplified as monodisperse dry granular flow and dual rigid barriers. The effects of basal clearance height on the impact dynamics are examined.

1 Introduction

Multiple barriers are advantageous on retaining large volumes of debris avalanches and debris flows compared with a single barrier because they can progressively arrest the flow and minimise the flow acceleration by facilitating the energy dissipation, thereby reducing barrier sizes. For closed-type multiple barriers [1], even flow with a small volume can be resisted by upstream barriers, resulting in an increase of maintenance work or a decrease of total retention capacity for next flow event. To optimise the design of multiple barriers, basal clearance [2–4] is usually constructed beneath the barriers to allow for discharge of flow (Fig. 1). Moreover, a basal clearance also serves to reduce the impact forces on barriers [5]. Despite the value of basal clearance, the design remains empirical.

In this study, impact dynamics of debris flow against multiple barriers have been investigated by conducting laboratory-scale flume model tests. The debris flows and multiple barriers were simplified as monodisperse dry granular flow and dual rigid barriers. The effects of basal clearance height on the impact dynamics are examined.
3 Results

3.1 Observed impact kinematics

Figure 3 shows the observed impact kinematics captured by the video camera for test where the first barrier had a height of \( H_{B1} = 2h_0 \) and basal clearance of \( H_c = 0.6h_0 \). A wide field of view was adopted to enable capturing the impact kinematics on both barriers. At \( t = 0.5 \) s, the basal discharge was approaching the second barrier and the overflow occurred on first barrier. At \( t = 1.2 \) s, the basal discharge impacted on the second barrier and the overflow from the first barrier landed on the basal discharge. The landed flow interacted with the basal discharge and flowed downstream to the second barrier (Fig. 3c). The initially arrested basal discharge by the second barrier formed a deposition and cushioned the subsequent impact. As the impact process continued, the deposited material behind the second barrier continued to accumulate and pileup to the upstream direction (Fig. 3d). At the end of the impact, the deposited material reached the basal clearance of the first barrier and blocked the discharge (Fig. 3e).

The observed impact kinematics indicate that the presence of a basal clearance can apportion the impacting flow against the first barrier from basal discharge and overflow. The basal discharge served as a soft loose material for the overflow to land and attenuate the kinetic energy. The basal discharge deposited on the second barrier also acted as a cushion layer for the subsequent overflow impact.

3.2 Measured impact force

Figure 4 shows the time histories of measured impact force on the second barrier for basal clearance heights beneath the first barrier ranging from 0.2 to 0.8. The impact force is normalised by the theoretical hydrodynamic impact force \( F = \alpha \rho v_1^2 h_0 w \), where \( \alpha \) is the impact coefficient and is selected as unity, \( \rho \) is the bulk density of the flow; \( v_1 \) is the impact velocity at the first barrier, \( h_0 \) is the impact flow depth at first barrier; \( w \) is the flow width. The normalised impact force indicates the ratio of impact force between the two barriers. With the presence of basal clearance, the impact force on the second barrier is influenced by both the basal discharge and overflow from the first barrier. As a result, the time history of the impact force shows two peaks during the impact, where the first peak is caused by the basal discharge and the second peak is caused by the overflow. With the increase of basal clearance beneath the first barrier, the impact force from basal discharge increases while the impact force from overflow decreases.
0.8h₀, the impact force on the second barrier increases because the impact force by basal discharge surpassed the impact force by overflow. This implies that the impact force on the second barrier for \( H_c/h₀ \leq 0.6 \) and \( H_c/h₀ > 0.6 \) can be estimated from the impact forces of overflow and basal discharge, respectively.

To characterise the governed impact force on the second barrier, Ng et al. [6] proposed an analytical approach to estimating the impact forces of overflow and basal discharge considering basal clearance height beneath the first barrier. The maximum impact force on the second barrier was considered as the maximum estimated impact force from overflow and basal discharge. By comparing with the measured maximum impact forces in this study as shown in Fig. 5, this proposed method performs reasonably well. More importantly, the proposed method captures the minimum impact force at \( H_c/h₀ = 0.6 \), indicating the potential for optimising the design of multiple barriers with an optimal basal clearance.

Fig. 5. Impact force on the second barrier for different basal clearance heights beneath the first barrier.

4 Conclusions

In this study, physical flume experiments were carried out to study the effects of basal clearance beneath the first barrier on the impact dynamics against dual rigid barriers. The basal clearance of the first barrier can regulate the impact force exerted on the second barrier by dissipating the kinetic energy of landing flow and apportioning the load contributions from basal discharge and overflow. The basal discharge governs the impact force when \( H_c/h₀ \geq 0.8 \), whereas the overflow governs the impact force when \( H_c/h₀ \leq 0.6 \). These two features indicate a minimum impact force on the second barrier when \( H_c/h₀ = 0.6 \). The two features also have been well captured by an analytical approach, which can serve to optimise the impact force on multiple barriers considering basal clearance height.

The work described in this paper was supported by the Research Grants Council of the Hong Kong Special Administrative Region, China (Areas of Excellence Scheme: AoE/E-603/18; Early Career Scheme Fund: 27205320).

References


