Influence of Debris Penetration on Impact Loading for Flexible Barrier Design

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**ABSTRACT**

Impact force from a debris flow is a key issue in the design of flexible barriers for debris flow mitigation. It is observed from previous field tests and real cases that slurry and small particles in a muddy debris flow can pass through the mesh net of a flexible barrier, which is, essentially, a significant advantage of the flexible barrier in mitigating debris flows. To quantitatively study the influence of debris penetration on the impact force, two large-scale tests were conducted using a dry granular debris flow and a saturated muddy debris flow to impact a flexible barrier respectively. The dynamic parameters of the generated debris flows and the impact forces on the flexible barrier in the two tests were measured and compared. The impact forces on the flexible ring net directly in the two tests are used in this paper to back-calculate the dynamic coefficients in the hydro-dynamic approach. It is found that the dynamic coefficient for the granular debris flow is much larger than that for the muddy debris flow. This finding indicates that the penetration of debris during the interaction with a penetrable flexible barrier can obviously reduce the dynamic impact on the flexible barrier.

1. INTRODUCTION

1.1 Flexible barrier

Flexible barriers are being increasingly applied to mitigate the danger of debris flows. Compared with other active measures, flexible barriers have several advantages: easy to install, cost-effective, eco-friendly and good adaptability in mountainous terrains. Therefore, as a potential alternative in natural hazard mitigation, flexible protection systems are valuable to be further studied.

1.2 Introduction of hydro-dynamic approach

The hydro-dynamic approach, first proposed by Hungr et al. (1984) and Armanini (1997), has been widely adopted in the flexible barrier design in Europe (Volkwein 2014) and Hong Kong (Kwan and Cheung 2012). According to this approach, the impact force is calculated as:

\[ F_{impact} = \alpha \rho_{bulk} v_0^2 hw \]  

where \( \rho_{bulk} \) is the bulk density of the debris flow (kg/m\(^3\)), \( v_0 \) is the debris flow velocity (m/s), \( h \) and \( w \) denote the flow depth (m) and the channel width (m), \( \alpha \) is a dynamic coefficient. The dynamic coefficient is the key parameter of the equation. Hungr et al. (1984) proposed a value of 1.5. Lo (2000) suggested the value of 3.0 in the design of rigid barrier. Wendeler (2008) suggested a value of 0.7 for mud flows and 2.0 for granular flows considering the flexibility and permeability of flexible barriers. Canelli et. al. (2012) recommended a value in a range between 1.5 and 5.0. It can be deduced that the impact forces calculated with Eq. (1) may vary due to the use of different values of the dynamic coefficients suggested by different researchers.

2. LARGE SCALE TESTS

2.1 Introduction of the large-scale device

A large-scale testing device is built in the Road Research Lab of the Hong Kong Polytechnic University with a length of 9.5 m, a height of 8.3 m and a width of 2 m. The view of the experiment setup is plotted in Fig. 1. This facility can be divided into 4 main components: (i) a reservoir with the capacity of 5 m\(^3\) at the top of the device,
(ii) a novel quick flip-up door opening system at the front vent of the reservoir, (iii) a flexible barrier with supporting posts and cables, and (iv) a flume linking the reservoir and the flexible barrier. The prototype flexible barrier with a width of 2.48 m is made up of steel rings with a diameter of 300 mm (No. ROCCO 7/3/300, Geobrugg), which are commonly used in rockfall mitigation in European and Hong Kong. This ring net is covered by a flexible secondary wire net with the mesh size of 50mm to provide a high trapping rate for the granular flows. Two parallel posts that can rotate in the plane of impact are installed to stretch and support the ring net, and each post is supported by two inclined strand cables. The flume has a length of 7 m, an inner width of 1.5 m and an inclination angle of 33 °. Side walls of the flume are made up of tempered glass to provide a clear observation of generated granular flows and their interactions with the flexible barrier.

Figure 1: Large scale physical model in PolyU

2.2 Instrumentation
To monitor the performance of a flexible barrier under the impact of granular flows, this device is instrumented with a well-arranged high-frequency measurement system. Two types of transducers are installed on the flexible protection system: mini tension link transducers and high capacity tension link transducers. The mini tension link transducers were calibrated in the soil laboratory with a maximum loading of 20 kN. Those transducers are installed on the flexible ring net to measure the impact force on the flexible ring net directly. Specifically, the central area of the flexible ring net, which consists of 5 connected rings, is separated from the main net and reconnected to the neighboring rings by 10 mini tension link transducers. A data-logger with the capability of sampling 48 transducers at 1000 Hz simultaneously is used to collect the data of all transducers. Two high-speed cameras capable of capturing a resolution of 1024 ×768 pixels at a sampling rate of 1000 frames per second are used to capture the motions of the granular flows and the deformation of the flexible barrier under impact. One high-speed camera is located at the right side of the barrier, and the other one is set in front of the barrier.

2.3 Test procedures
A granular debris flow impact test and a muddy debris flow impact test were conducted with this large-scale device. In the test, the debris flow travelled on the steel plate of the flume and impacted an empty flexible barrier. At the beginning of test, the door was flipped up in less than 0.5 s with the help of a novel door opening system to generate a uniform granular flow. The datalogger started to obtain data several seconds before the triggering of the debris flow to obtain initial values of all the transducers. Simultaneously, the high-speed cameras started to capture the motion of the debris flow and its interaction with the flexible barrier during the impact. The impact velocity of the granular debris flow was measured by the moving distance between two continuous photographs taken by the side-view high-speed camera with the assistance of scale reference attached to the supporting post and frame.

3. TEST RESULTS
3.1 Granular debris flow
The granular material used in this test is uniform dry aggregate with the diameter between 15-30 mm. The measured impact velocity of the granular debris flow is 5 m/s. The impact and deposition process of the granular debris flow impacting a flexible barrier is plotted in Fig. 2 by high-speed cameras. It can be observed that the granular debris flow impacted the flexible barrier and piled up first, then deposited behind rest granular deposition layer by layer. During the deposition process, no obvious penetration of granular particles was observed. The impact force on the flexible barrier directly was measured from the mini tension link transducers installed on the flexible ring net. The measured impact force in this test was 10.96 kN. From the back-calculation using the hydro-dynamic approach, the dynamic coefficient is around 2.0.

![Figure 2: Impact process of granular debris flow in (a) Side view (red lines represent the profile of the granular debris flow) and (b) Front view](image)

3.2 Muddy debris flow
The debris material used in this test is completely decomposed granite (CDG) soil mixed with abundant water. The measured impact velocity of the muddy debris flow is 7 m/s. The impact process of the muddy debris flow on a flexible barrier is plotted in Fig. 3 by high-speed cameras. It can be observed that a certain percentage of slurry and small particles passed through the flexible barrier with a residual velocity during the impact, and only a small percentage of large debris was trapped by the secondary mesh net of the flexible barrier. The measured impact force in this test was 6.01 kN. From the back-calculation using the hydro-dynamic approach, the dynamic coefficient is around 0.5.
CONCLUSIONS

From the test results, the muddy debris flow has a better fluidity and a faster impact velocity than those of the granular debris flow, but a lower impact force on the flexible barrier than that of the granular debris flow. Obvious penetration only occurred in the muddy debris flow impact test. From the back-calculation, it can be concluded that the dynamic coefficient for muddy debris flow has a lower value of 0.5, which is much smaller than the coefficient for granular debris flow with the value of 2.0. The comparison shows that the granular debris flow can lead to a higher impact even with a lower velocity since the hydro-dynamic approach assumes the dynamic impact force is proportional to the velocity squared. From the observations of the impact process, it can be concluded that the impact force has a close relationship with the penetration of debris material.

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REFERENCES