Contribution of Fluid-phase Pressure to Two-phase Flow Impact

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ABSTRACT

Estimation and measurement of the debris flow impact load on structures is essential for design of structural countermeasures and is also an important approach to study the fundamental dynamic properties of debris flows. Due to the destructive power of debris flows, the contribution of fluid-phase impact pressure to the total impact pressure on engineering structure has not been reported. This study utilizes a small-scale flume to study two-phase flow impact on a rigid barrier. Test results show that, for the low solid fraction flow, the flow remains fully liquefied during the transportation and impact processes. The fluid-phase impact pressure contributes most of the total normal impact pressure. This indicates that quantification of solid-fluid interaction is vital for the design of debris-resisting structures.

1 INTRODUCTION

Debris flow is one of the major hazards in the mountainous areas which carries huge amount of momentum and causes series damage to the infrastructure downstream. The fluid among the debris flow grains plays the role to reduce the grain-contact stresses and thus enhance the mobility. Estimation and measurement of the debris flow impact load on structures provide the basic information for design of structural countermeasures. More than that, it is also an important approach to study the fundamental dynamic properties of debris flows.

The basal normal stress and pore pressure have been reported in the literature (Iverson et al. 2010; McArdell et al. 2007). However, due to the destructive power of debris flows, the contribution of fluid-phase pressure to the total impact pressure on engineering structure has not been revealed. In this study, two-phase debris flow impact on a rigid barrier was conducted in a small-scale flume. Measurement of fluid-phase impact pressure could shed light on the two-phase flow impact mechanisms.

2 METHODOLOGY AND RESULTS

2.1 Flume modelling of two-phase flow impact on a rigid barrier

The tests were conducted using a 9.0 m long and 0.3 m wide flume. The flume has a 3.0 m upstream section with 25° slope and a 6.0 m downstream section with 5° slope. A rigid barrier is fixed perpendicular to the 5° slope as a cantilever structure. To prevent overflow of two-phase flows during impacting rigid barrier, the heights of both the sidewall and the barrier were designed as 0.8 m. A series of sensor ports are installed with their upper surface flush with the base of flume. The sensor port is composed of one triaxial load cell for measurement of basal normal and shear stresses and one pore pressure transducer (PPT) for measurement of dynamic pore pressure. Instrumentation on the rigid barrier includes miniature load cells for the total normal impact pressure and PPTs for the fluid-phase impact pressure.

The two-phase flows are mixtures of 0.6 mm glass beads and viscous fluid. The fluid is a mixture of glycerin and water with a viscosity of 0.1 Pas in this study. The total volume of two-phase mixtures is controlled as 50 liters. The solid fraction varies from 0.4 to 0.6 to investigate the effects of solid-fluid interaction on the flow impact dynamics. Test program is summarized in Table 1.
Table 1: Test program of two-phase flow impact on rigid barrier

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Viscosity (Pas)</th>
<th>Volumetric solid fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>S4</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>S5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>S6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

2.2 Basal stresses and pore pressure

Figure 1 shows the time histories of the basal normal stress, basal shear stress, and basal pore pressure of Test S4 in the 3.0 m section of the flume. The initial time (0.0 s) of all tests is readjusted as the moment of release of debris. It is obvious that the pore pressure overlaps with the normal stress, indicating that the flow is fully liquefied. The solid fraction 0.4 is lower than the critical solid fraction (Iverson and George 2014), so that the solid phase contracts during the flow process and the viscous effect of fluid phase dominates the flow dynamics (Song et al. 2017). The basal shear stress shows a sharp increase and followed by a gradual decrease before the peak normal stress (peak flow depth). The velocity of flow reaches its maximum in the flow front and attenuates subsequently. For the fully liquefied case, the viscous drag (proportional to the square of velocity) mainly contributes to the basal shear force.

Figure 1: A fully liquefied case of two-phase impact (S4)

2.3 Impact kinematics

The overall captured impact kinematics is fluid-like (Fig. 2). As the flow reaches the base of rigid barrier, an instant runup appears. The debris jets up along the barrier, reaching the crest of the barrier (0.8 m) and then falls back to the upstream direction.
Figure 2: Observed interaction kinematics for Test S4 (a) $t = 0.0$ s; (b) $t = 0.1$ s; (c) $t = 0.2$ s; and (d) $t = 0.3$ s. The initial time is set as the moment when the flow reaches the barrier base.

2.4 Total normal impact pressure and fluid-phase impact pressure

Figure 3: Total normal and fluid-phase impact pressures of Test S4

Figure 3 shows the total normal impact pressure and the fluid-phase impact pressure at the base of rigid barrier for Test S4. The fluid-phase pressure generally follows the trend of the total impact pressure, which is
consistent with the finding in the basal stresses measurement. This indicates that the impact dynamics of the flows with low solid fraction may be dominated by the fluid phase and quantification of solid-fluid interaction is vital for the design of debris-resisting structures.

3 CONCLUSIONS

A series of small-scale flume tests were carried out to investigate the contribution of fluid-phase impact pressure to the debris flow impact. It is found that, for the low solid fraction flow impact, the fluid phase dominates the impact behavior. The flow remains fully liquefied during the transportation and impact processes, and the fluid-phase impact pressure contributes most of the total normal impact pressure. This study utilizes uniform grain size and ideal Newtonian rheology for the fluid phase. Effects of grain size distribution and nonlinear fluid rheology deserve in-depth investigation.

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REFERENCES


