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A monitoring barrier for investigating debris flow/structure/ground interactions

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Alpine regions are exposed to different mass wasting processes, including debris flows, landslides, and rock fall. Debris flows are highly mobile gravity driven mixtures of sediment and water. The combination of high velocities and the capacity to carry large boulders endangers human lives and infrastructures. For the design of mitigation measures a realistic design value of the expected impact pressure is required, but not yet available. Due to the destructive power of debris flows real scale data are rare. For this reason, a new monitoring barrier was built in the Gadria creek in South Tyrol, Italy, to measure the interaction between debris flows, the engineering structure and the ground. In total more than 50 sensors were installed measuring flow properties like flow depth, normal stress, shear stress, pore fluid pressure and the internal velocity profile, as well as the impact pressure onto the barrier structure. In the first year of operation (2017) two small debris flows were recorded with a maximum flow depth of around 1 to 1.5 m. Variations of flow depth go in line with normal stress and fluid pressure. For the two events densities ranged from 1,800 to 2,000 kg/m³ and for some sections of the flow the material was close to liquefaction. Though flow depth and velocities were rather small, impact pressures were up to 40 kPa. The outcomes from our monitoring efforts will improve engineering design criteria and may also provide a benchmark for debris flow model testing.

debris flow, monitoring, check dam

Контрольно-измерительный барьер для исследования взаимодействия селя с сооружениями и земной поверхностью

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Альпийские районы подвергаются различным процессам массовых смещений материала, таким как сели, оползни и обвалы. Сели представляют собой высокомобильные смеси наносов и воды. Сочетание высоких скоростей и способность переносить большие валуны ставят под угрозу жизнь людей и инфраструктуру. Для разработки мер по смягчению требуется реалистичное расчетное значение ожидаемого ударного давления. Из-за разрушительной силы обломков реальные данные реальной величины давления редко удается получить. По этой причине в русле Гадрии в Южном Тироле, Италия, был построен новый барьер для измерения взаимодействия между селевыми потоками, инженерными конструкциями и землей. Всего было установлено более 50 датчиков, измеряющих такие свойства потока, как глубина, нормальное напряжение, напряжение сдвига, давление поровой жидкости и профиль внутренней скорости, а также ударное давление на барьерную конструкцию. В первый год работы (2017 г.) были зарегистрированы два небольших селя с максимальной глубиной потока около 1-1,5 м. Вариации глубины потока идут в соответствии с нормальным напряжением и давлением жидкости. Для двух событий плотность составляла от 1800 до 2000 кг/м^3, а на некоторых участках потока материал был близок к сжижению. Хотя глубина и скорость потока были относительно небольшими, ударное давление составляло до 40 кПа. Результаты наших мониторинговых работ улучшат критерии инженерного проектирования и могут также стать эталоном для тестирования модели селевых потоков.

сель, мониторинг, контрольно-измерительный барьер

Introduction

Monitoring represents the backbone of investigations of the scientific community on mass wasting processes like debris flows. The observation of real events provides high quality information of essential parameters like rainfall thresholds or depth of discharge and gain essential insights to general behavior. The information from monitoring stations helps to guide the development of simulation models and to improve hazard assessment.

For the design of structural mitigation measures the knowledge of flow depth, density, velocity, impact force and total discharge are needed *[Arattano & Marchi, 2000*]. Since debris flows are mixtures of sediment and water the impact forces are expected to comprise the dynamic fluid pressure as well as single impact forces by particles. The measurements of these parameters pose a challenge for the scientific community. Only some efforts were done in the past to quantify these parameters in real scale [e.g. *Hu et al., 2011; Zhang, 1993; Suwa et al., 1973; Bugnion et al., 2012*].

Following a hydrodynamic approach, the main factors of the impact pressure (P in N/m²) are density ρ in kg/m³), velocity (v in m/s), and an empirical coefficient α which takes into account the impacts of grains additionally to the fluid pressure. This coefficient typically varies between 0.4 and 2 in real scale applications and up to 12 in small scale experiments.

$$P = \alpha \cdot \rho \cdot v^2. \qquad (1)$$

Furthermore, several studies relate the impact forces of debris flows to the Froude number [e.g. *Hübl et al., 2009; Armanini et al., 2011*]. By determining the effect of the Froude number (ratio of inertial forces to gravitational forces), *Hübl et al.*, [2009] illustrate by analysing a scale free relationship of the normalized empirical value of the hydrodynamic model and the normalized impact forces, that the hydrodynamic model does not perform well by low Froude regimes. Overall, these studies highlight the need for data densification of real scale debris flow impact in low Froude regimes, to investigate the complexity of impact forces.

Method

In 2016, a monitoring barrier was built to investigate the check dam/debris flow interaction. The check dam is situated in the Gadria torrent in South Tyrol, Italy, which is prone to frequent debris flow events due to a high sediment availability in the upper catchment [*Comiti et al., 2014*]. More than 50 sensors were installed measuring flow properties like flow depth, normal stress, shear stress, pore fluid pressure and the internal velocity profile, as well as the impact pressure onto the barrier structure [*Nagl & Hübl, 2017*].

Fig. 1. Monitoring Barrier with fourteen load cells on the front

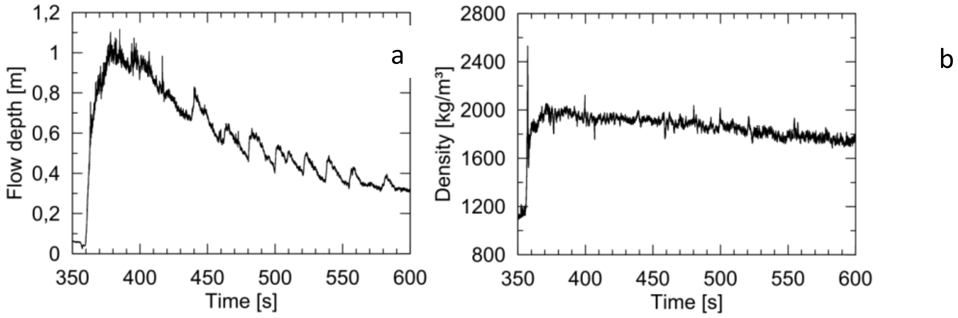
The monitoring barrier consists of a single concrete element covered with steel plates in the middle of the channel with fourteen load cells on the front of the barrier. The load cells can measure impact pressures up to 2,000 kN, see Fig. 1. The sampling frequency of each load cell is 19,200 Hz. To measure the normal force, one force plate was installed in front and one 2 m aside of the barrier, both recording with a sampling frequency of 2,400Hz. Additionally, ultrasonic sensors above the force plates are used to determine the flow height.

Two debris flows were successively recorded with a maximum flow depth of around 1 to 1.5 m in the year 2017.

Data

Herein, we present preliminary results of in-situ measurement of the first events in 2017. The first debris flow was triggered on the 10th of July 2017 during an intense, short duration rainfall of about 12 mm. The hydrograph of the debris flow was marked by one main surge (Fig. 2a). The antecedent part was characterized by a steep boulder-rich front, followed by a more dilute tail with fewer boulders visible on the surface. Video analysis showed that the surface particles moved faster than the bulk velocity and were thus transported to the front. At the front small boulders were overrun, and bigger particles pushed forward, similar as described by Pierson [1986]. From the video recording and measurements of the basal pore fluid pressure we assume that the interstices between the solids were filled with muddy slurry.

The density, which was calculated from the normal stress and flow depth measurements decreased from more than 2,000 kg/m³ at the front to 1,500 kg/m³ at the tail of the flow, illustrated in Figure 2b. This observation is in accordance with other monitoring results [*McArdell, 2016; McCoy et al., 2013*], and is related to the focusing of large particles at the front.



(a) (b)

Fig. 2. Flow depth (a) and density (b) of debris flow event on 10th of July 2017

Particle tracking based on the digital video material was carried out to determine a time series of surface velocities. We find that the surface velocity first quickly increased to a value of around 1.3 m/s, and then decreased to fluctuate around 1 m/s (Fig. 3).

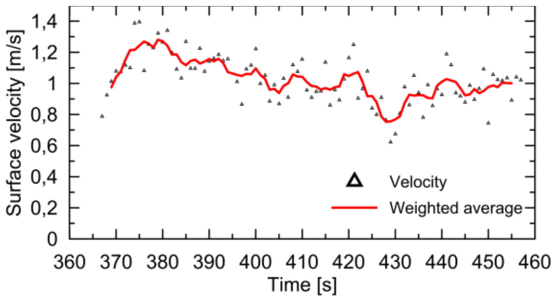


Fig. 3. Surface velocity during the impact

During the event, four load cells were exposed to the flow and measured impact pressures at different heights. A moving average filter of 19,200 smoothed each time series to reduce the high noise and the influence of particle impact (Fig. 4). The maximum impact force values and corresponding stress values (by dividing impact force with the area of 0.031 m² of the load plate) are shown in Table1. The lowest load cell 1 shows the highest forces at the beginning up to 1 kN. At increasing height of the load cells the impact forces decrease.

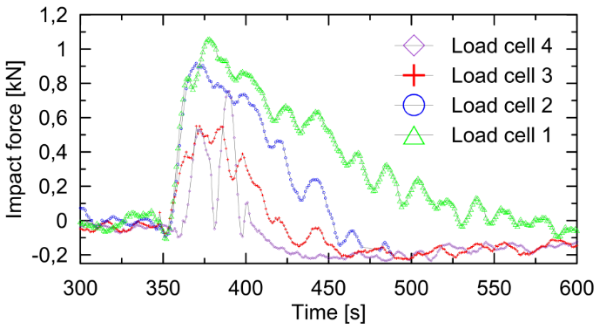


Fig. 4. Impact pressure.

Table 1. Measured impact force and impact pressure of four load cells.

	Load cell 1	**Load cell 2**	**Load cell 3**	**Load cell 4**
Max. impact force [N]	1,058	917	551	754
Max. impact pressure [N/m²]	33,710	29,214	17,558	24,042

We also back-calculated the empirical coefficient α for the hydrodynamic impact model for the four loads cells by rearranging equation 1. Taking the derived density and the velocity during the impact into account, α ranged between 5.2 and 10.0, illustrated in Table 2. The Froude number of this event was about 0.38.

Table 2. Empirical value α of the hydrodynamic impact model.

	Load cell 1	**Load cell 2**	**Load cell 3**	**Load cell 4**
α	10.0	8.6	5.2	7.1

Discussion

Data from previous studies based on small-scale experiments [*Scheidl et al., 2013; Cui et al., 2015; Zanuttigh & Lamberti, 2006; Kim et al., 2013; Hübl & Holzinger,2003; Watanabe & Ikeya, 1981*] and real-scale measurements [*Bugnion et al., 2012; Hu et al., 2011*] suggest a dependence of the empirical value on the Froude number. The data from this study show high back-calculated empirical value for the hydrodynamic model in Fig. 5 in the low Froude regime and indicate a problem of the hydrodynamic model in low Froude regimes.

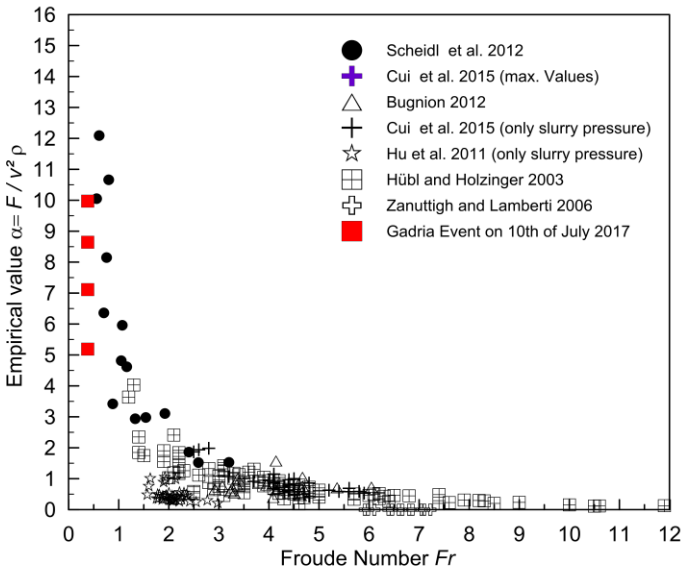


Fig. 5. Froude number vs empirical value

There is abundant room for progress in determining further investigations to illuminate the connection of the Froude number on the dynamic behaviour of debris flows.

Conclusion

In this paper, we present the first preliminary results of in-situ measurement of the debris flow impact pressures in the Gadria torrent. The small event showed densities from 2,000 to 1,500 g/m³ and velocities up to 1.3 m/s at the front. Impact forces on the front were up to 1 kN. The measured forces highlighted the problem of the empirical coefficient of the hydrodynamic model in low Froude regimes. Further in-situ real time measurements also will help to densify the database of real scale debris flows and improve hazard assessments.

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