SSM
Scuola Superiore Meridionale

MERC PhD Project Proposal

Title of the research project

Hydrogeological and volcanic risks. Protection from catastrophic granular flows.
Sub-title. Modelling the impact of granular flows on protective structures and building

Keywords

Granular flows, modelling of impact, cellular automata, land protection, structural damage

Supervisors

Supervisor 1
Gianfranco Urciuoli, ***gianurci@unina.it***, ***homepage***, *land safety (slope stability, hydrogeological risk)*

Supervisor 2
Iunio Iervolino, ***iunio.iervolino@unina.it***, ***homepage***, *earthquake engineering and seismic risk*

Supervisor 3
Warner Marzocchi, ***warner.marzocchi@unina.it***, ***homepage***, *geophysics and natural hazard forecasting*

Project description

TOPIC

The scientific literature largely treats with different types of potentially destructive water-saturated mass-flows occurring in mountainous regions and in areas where steep slopes cut down in loose sediment. These mass-flows, that often involve volcanic soils, can be divided into different categories using sediment concentration, grain-size distribution and bulk density. Depending on their characteristics, they are named lahars, debris flows, flow-slides, debris avalanches, hyper-concentrated flows,….

In all the cases, the landslide body is constituted of water, soil particles and sometimes rock boulders carried by liquid. Movements are very complex, because their mass varies along the path: it may increase for the erosion or decrease due to sedimentation. As a consequence the size, the velocity and the proportion of rock debris mixed with water constantly change. The impact with any type of obstacle depends on the i) Topography of the ground-surface, ii) Rheological and kinematic characteristics of the mass-flow and iii) Geometry and deformability of the obstacle. At the impact, the geometry and the velocity of the mass-flow front vary depending on factors at points i) and iii).

The topic proposed for the PhD thesis concerns modelling the impact of these mass-flows on different obstacles using cellular automata, to predict expected damages and to mitigate hazards through engineered protection structures. Cellular automata are able to model the mutual interrelationships between the various factors involved in the impact and the non-linearity of the underlying equations.

KEY RESEARCH QUESTIONS

The described mass-flows share several characteristics and effects with floods, but fewer studies have analysed the wide range of physical impacts that they produce. Existing studies are

fragmented and devoted to a single type of flow. The innovative idea of this project consists of individuating and modelling common characters considering the mutual interaction among the factors influencing the impact, in particular the variation of a) Geometric, b) Rheological and c) Kinematic characteristics of the landslide front at the impact and the d) Deformation of obstacles.
For all the mass-flows considered, damages are induced by three principal forces driving impacts: (1) Hydrodynamic pressure, (2) Hydrostatic pressure, and (3) Collisional forces due to boulders. These quantities depend on the characteristics of the landslide front listed above (a, b, c).
About properties of the material involved in the landslide body, there are several studies listed in the section devoted to the state of the art, but at present there is no approach useful to analyse movements and impacts with a unitary physical-mathematical approach and to consider interrelation among influencing factors.

ASPECTS TO BE CONSIDERED

Some aspects, often neglected in the modelling, have to be carefully considered in this project and may give rise to important developments in conceiving new protection control systems.

- The impact force decreases significantly if the deformability of the obstacle increases.
- A liquid-granular wave hitting a vertical obstacle produces two different impact dynamics (Armanini et al., 2011): high-velocity fronts are deviated in the vertical direction, producing a vertical jet-like bulge, whereas low-velocity fronts are reflected in direction oblique to the obstacle. This difference has profound consequences on the exposure of obstacles with respect to incoming flows.
- Impacts will differ in space and time according to the sections of the flow (head, body or tail) that encounter an obstacle.

PROJECT OBJECTIVES

The objective of this project consist of all or one of the following topics:

- investigating how flow characteristics and processes lead to damage mechanisms on buildings, infrastructure and lifelines, exploring the broad range of valuable assets impacted;
- modelling the impact of the mass flow with various types of obstacles to analyse stresses induced in the structures;
- ideating protective control works to stop or divert the mass flow, to safeguard areas downstream.

STATE OF THE ART

Models set up by Proske et al. (2011), Armanini et al. (2011), Zeng et al. (2015) and Gao et al. (2017) are useful for defining mechanical impacts, failure moments, and the response of damaged structures. Coupled with rheological tests on the material and validation against real case studies, model outcomes lead to a critical retrospective analysis of input parameters; e.g. using a Bayesian approach to check model validity, enabling both scientists and end-users to assess hazards (Tierz et al., 2017; Charbonnier et al., 2018a).
Hazards on buildings and infrastructure have recently been the focus of specialized papers, e.g. ash fall (Wilson et al., 2012), pyroclastic density currents (Jenkins et al., 2013), snow avalanches (De Biagi et al., 2015, Calianno et al., 2013). Other relevant papers are due to: Jenkins et al. (2015), Wilson et al. (2014, 2017); Zuccaro and De Gregorio (2013a, 2013b, 2015) and Deligne et al. (2017).
Hydraulic characteristics of flows and solid/liquid concentrations were defined in early classifications (Costa, 1984, 1988; Coussot and Meunier, 1996; Iverson, 1997; Lavigne and Thouret, 2000), while rheological parameters were further measured using small-scale experiments, laboratory testing (Ancey, 2007; Hübl et al., 2009; Dumaisnil et al., 2010), and large-scale experiments carried out in channels (Rickenmann, 1999; Doyle et al., 2010, 2011; Zhou and Ng, 2010) or experimental flumes (Iverson et al., 2010, 2011).

Relevance to the MERC PhD Program

Briefly describe how this project fits within the scope of the MERC PhD program describing its interdisciplinary aspects, relevance in application and beneficiaries.

RELATION WITH THE SCOPE OF MERC PHD
In the previous paragraph it was briefly explained as this project considers a complex problem involving interrelated systems (variable mass-flows, buildings,…). The cellular automata code is suitable for the simulation of completely subaerial mass-flows considering main features of these movements such as erosion and deposition and triggering of secondary landslides along the path, presence of structures and buildings, impulsive loss of matter (water and finer grains) and energy dissipation at impact. Moreover, buoyancy effects, drag forces and peculiar mechanisms like hydroplaning are also modeled.
SOCIAL RELEVANCE AND ENGINEERING APPLOICATIONS
Territory, with its inhabitants, networked infrastructures, buildings and other exposed goods is one of the most complex socio-technical system. Territory fragility and questionable management policies make the occurrence of natural hazards a major source of social risk. In particular hydrogeological risk is worrying because damage scenarios can be amplified by climate change.
Until now interactions between environmental/natural processes and anthropic actions have produced a progressive increase of risk on the territory, because many new assets have been settled in areas at risk. Now it is the time to proceed with the protection of the exposed goods.
The risk mitigation linked to hydrogeological and volcanic phenomena is very critical since it requires economical resources, that are often unavailable, to intervene on vulnerable elements, such as infrastructure in areas at risk. Research is needed to improve possibilities and efficiency in practical applications.
For mitigating hydrogeological and volcanic risks affecting territory an integrated and trans-disciplinary approach needs. In this project geotechnical, volcanic and structural competence have been involved.
BENEFICIARES
The types of public beneficiaries are: Local authorities and public administrations, Soil Reclamation Consortia, Entities managing protected areas, Public Components of the Civil Protection System, Associations of civil protection volunteering**.**
The types of industrial beneficiaries are: construction companies; barrier manufactures and related industries.

Key references

Armanini, A., Larcher, M., Odorizzi, M., 2011. Dynamic impact of a debris flow against a vertical wall. Ital. J. Eng. Geol. Env. 3B, 1041–1049.

Charbonnier, S.J., Macorps, E., Connor, C.B., Connor, L.J., Richardson, J.A., 2018a. How to correctly evaluate the performance of volcanic mass flow models used for hazard assessment? In: Thouret, J.-C.(dir.) (Ed.), Hazard and Risk Mapping – The Arequipa–El Misti Case Study and Other Threatened Cities. Presses universitaires Université Clermont-Auvergne, Territoires H.-S. 1, pp. 15–20 153 pp.

Gao, L., Zhang, L.M., Chen, H.X., 2017. Two-dimensional simulation of debris flow impact pressures on buildings. Eng. Geol. 226, 236–244.

Proske, D., Suda, J., Hubl, J., 2011. Debris flow impact estimation for breakers. Georisk Assess. Manage. Risk Eng. Syst. Geohazards 5 (2), 143–155.

Zeng, C., Cui, P., Su, Z., Lei, Y., Chen, R., 2015. Failure modes of reinforced concrete columns of buildings under debris flow impact. Landslides 12, 561–571.

Tierz, P., Woodhouse, M.J., Phillips, J.C., Sandri, L., Selva, J., Marzocchi, W., Odbert, H.M., 2017. A framework for probabilistic multi-hazard assessment of rain-triggered lahars using Bayesian belief networks. Front. Earth Sci. 5, 73.

Joint supervision arrangements

The PhD thesis foresees trans-disciplinary parts, which concern above all the preliminary design of the research work and scientific comments on results. For these parts the student will be jointly supervised by the three supervisors during plenary meetings that will be held roughly every two months.
To develop the monothematic parts of the work, the student will be supervised in turn by one of the supervisors with whom meetings will be more frequent (weekly or bi-weekly).

Location and length of the study period abroad (min 12 months)

Italian and foreign collaborating institutions:

Politecnico di Torino. Prof. Claudio Scavia - claudio.scavia@polito.it

University of Strathclyde Glasgow. Prof. Alessandro Tarantino – alessandro.tarantino@strath.ac.uk,

ETH Zurich, Sarah M. Springman - sarah.springman@sl.ethz.ch

The student is expected to travel abroad during the second year of the PhD program.

Any other useful information

Industrial partners:

Geobrugg Italia s.r.l. via XXIV Maggio 17 Bergamo Italy

Geobrugg AG Aachstrasse 11, Romanshorn, Switzerland

Gruppo industriale Maccaferri, Via degli Agresti, 6 Bologna Italy

Other Research Institutions:

Istituto Superiore per la protezione e la Ricerca Ambientale (ISPRA), via Vitaliano Brancati 48, Roma Italy

CNR IRPI Istituto per la protezione idrogeologica, via Madonna Alta 126, Perugia

Funded projects related to the proposed project:

Progetto di Ricerca Industriale e non preponderante Sviluppo Sperimentale, area di specializzazione “Smart Secure & Inclusive Communities”, codice identificativo ARS01_00964 dal titolo “MitiGO - Mitigazione dei rischi naturali per la sicurezza e la mobilità nelle aree montane del Mezzogiorno”: 275.000 euros.