Date of Submission	14 December 2021

IPL Project Proposal Form 2022

1. Project Title: **Investigation of landslide initiation caused by rainfall infiltration using small-scale physical and numerical modeling (ILIRIM)**
2. Main Project Fields

   Select the suitable topics. If no suitable one, you may add new field.

   (1) Technology Development

   A. Monitoring and Early Warning, B. Hazard Mapping, Vulnerability and Risk Assessment

   (2) Targeted Landslides: Mechanisms and Impacts

   A. Catastrophic Landslides, B. Landslides Threatening Heritage Sites

   (3) Capacity Building

   A. Enhancing Human and Institutional Capacities

   B. Collating and Disseminating Information/ Knowledge

   (4) Mitigation, Preparedness and Recovery

   A. Preparedness, B. Mitigation, C. Recovery

   (5) Landslide Modeling

   A. Physical modeling, **B. Numerical modeling**
3. Name of Project leader: **Josip Peranić, PhD**

Affiliation: University of Rijeka, Faculty of Civil Engineering; Postdoc

Contact: Radmile Matejčić 3, 51000 Rijeka, Croatia; +385 51 265 943; josip.peranic@gradri.uniri.hr

Core members of the Project

Željko Arbanas/ University of Rijeka, Faculty of Civil Engineering, Head of Geotechnical Chair, Full Professor; zeljko.arbanas@gradri.uniri.hr

Vedran Jagodnik/ University of Rijeka, Faculty of Civil Engineering, Head of Geotechnical Laboratory, Associate Professor; vedran.jagodnik@gradri.uniri.hr

Martina Vivoda Prodan/ University of Rijeka, Faculty of Civil Engineering, Assistant Professor; martina.vivoda@gradri.uniri.hr

Sanja Bernat Gazibara/ University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Postdoc; sanja.bernat@rgn.unizg.hr

4. Objectives: Investigate the hydro-mechanical response of slopes exposed to rainfall using a newly developed platform for testing small-scale physical landslide models under 1g conditions; Use the data obtained together with numerical modeling to investigate the role of rainfall characteristics, soil hydro-mechanical properties, geometric and boundary conditions in landslide initiation by rainfall; Investigate the applicability of the adopted research methodology in defining rainfall threshold values.
5. Background Justification: Despite the considerable progress made in recent decades, understanding the physical processes and mechanisms responsible for rainfall-induced landslides remains a hot topic for

the landslide scientific community. Some of the aspects contributing to the complexity of the problem are related to the highly nonlinear material properties of the soils involved, quantification of boundary conditions, hysterical soil effects, spatial and temporal variation of rainfall characteristics, etc. Small-scale physical landslide models, in combination with advanced monitoring techniques, allow accurate observation of the hydraulic and mechanical response of slopes under precisely controlled initial and boundary conditions. This makes them a valuable tool for the accurate measurement of quantities and variables controlling instability phenomena. At the same time, they provide high-quality data for the validation and calibration of analytical solutions and numerical models.

6. Study Area: The research activities will be carried out in the Geotechnical laboratory of the Faculty of Civil Engineering, University of Rijeka. The results will be applicable to the research topic in general.
7. Project Duration: 4 years
8. Resources necessary for the Project and their mobilization

   Personnel: Four (4) senior researchers, four (4) young researchers, graduate students, one (1) laboratory technician; Facilities: Fully equipped geotechnical laboratory for basic and advanced soil and rock testing, platform for testing small-scale physical landslide models under 1g conditions with rainfall simulator and advanced monitoring equipment (available under ModLandRemSS research project), numerical modeling software (Rocscience, LS Rapid, GeoStudio); Budget: 25,000 USD.
9. Project Description: One of the main objectives of the four-year research project "Physical modeling of landslide remediation constructions' behavior under static and seismic actions", which started in October 2018 at the Faculty of Civil Engineering, University of Rijeka, Croatia, was to develop an advanced platform for physical modeling of small-scale slopes under 1g rainfall conditions. The newly developed platform, equipped with advanced geodetic and geotechnical monitoring systems, enables precise monitoring of displacements and changes in soil moisture and pore pressure of scaled slopes exposed to different simulated rainfall events (Pajalić et al. 2021). The main idea of this project is to use the platform to study the hydro-mechanical response of scaled slopes composed of different soil types, conditions and geometries while subjected to different rainfall loads. The different soil types will be achieved by mixing clean sand as the base slope material with varying amounts of kaolin. This ensures repeatability of tests under controlled installation, geometry, and boundary conditions (BCs) on soil mixtures representative of the behavior of different soil types: from non-plastic, purely frictional sands to cohesive, clayey soils. The data collected on the hydraulic and mechanical behavior of slopes under specific test conditions and rainfall loads will be analyzed and interpreted. Understanding the triggering mechanisms as well as the mathematical description of the processes controlling the transient infiltration process and its effects on slope stability require a complete knowledge of the relevant soil properties. A further important step is therefore an advanced hydromechanical characterization of the soils used in the study. Some of the required tests include the determination of basic soil properties and soil classification. Some of the available devices for determining water retention curves (WRCs), hydraulic conductivity functions (HCFs) and (un)saturated shear strength properties are conventional and modified, axis-translation based oedometers, triaxial (TX) and direct shear apparatuses (DSA), ring shear apparatus, mini tensiometers, moisture content sensors, etc. The

experimentally obtained data and the identified soil properties will be used to calibrate advanced numerical models. Various numerical studies and parametric analyses will investigate the response of slopes under BCs different from those used in the experiments conducted. The results obtained could also be useful to study the role of different variables and define rainfall thresholds for landslide initiation by rainfall.

10. Work Plan/Expected Results: The work plan consists of the following four main phases:

    1st phase: Conducting 1g physical model tests of small-scale landslides with different soil types, geometric and initial moisture conditions, and predefined rainfall conditions: PHYSICAL SMALL-SCALE LANDSLIDE MODELING; Milestone: Obtain data on the hydraulic and mechanical behavior of small-scale landslides under specified test conditions and rainfall loads.

    2nd phase: Analysis of data collected in phase 1, including changes in soil moisture, pore water pressure (positive and matric suction), temperature and landslide movement data: DATA ANALYSIS; Milestone: Analysis and interpretation of data collected from in phase 1.

    3rd phase: Laboratory tests for advanced hydro-mechanical characterization of soils used in small-scale physical landslide models: SOIL TESTING; Milestone: Define material properties required for the interpretation of experimentally obtained results and perform advanced numerical analyses, including: (i) classification and basic soil index properties; (ii) advanced hydraulic characterization of soils, including WRCs and HCFs; and (iii) determination of (un)saturated shear strength properties.

    4th phase: Use the obtained data to perform advanced numerical analyses of rainfall infiltration and slope stability: NUMERICAL MODELLING; Milestone: Use the data obtained in phases 2 and 3 to calibrate numerical models and perform various numerical studies and parametric analyses. Investigate the possibility of using the data obtained to derive rainfall threshold values.

11. Deliverables/Time Frame:

    1st phase: 1g physical model tests of small-scale landslides conducted for different soil types and test conditions. Time duration: within the first two years of the project.

    2nd phase: Data on the hydraulic and mechanical response of small-scale slopes under simulated rainfalls collected, analyzed and interpreted. Time duration: within the first two years of the project.

    3rd phase: Tests for determination of basic soil properties, soil classification and advanced hydro-mechanical characterization performed. Time duration: during the third and fourth year of the project.

    4th phase: Numerical analyses to investigate the hydraulic response of slopes under different rainfall conditions and the triggering mechanisms of rainfall-induced landslides performed. Time duration: during the third and fourth year of the project.

12. Project Beneficiaries: Landslide-affected population, practitioners and scientists dealing with landslides, through new scientific knowledge on rainfall-induced landslides; Researchers involved in the project through gaining valuable experience and knowledge in the field of conducting experiments, soil testing, numerical modelling and triggering mechanisms of landslides initiated by rainfall in general; Institutions and working groups involved in the project through increasing their visibility and capacity.

13. References:

Peranić J, Mihalić Arbanas S, Arbanas Ž (2021) Importance of the unsaturated zone in landslide reactivation on flysch slopes: observations from Valići Landslide, Croatia. *Landslides* 18, 3737-3751

Pajalić S, Peranić J, Maksimović S, et al (2021) Monitoring and data analysis in small-scale landslide physical model. *Appl Sci* 11(11):5040.

Jagodnik V, Peranić J, Arbanas Ž (2021) Mechanism of Landslide Initiation in Small-Scale Sandy Slope Triggered by an Artificial Rain. In: Arbanas Ž, Bobrowsky P T, Konagai K, Sassa K, Takara K. (eds) *Understanding and Reducing Landslide Disaster Risk*. WLF 2020. Springer, Cham. pp 177-184.

Peranić J, Moscariello M, Cuomo S, Arbanas Ž (2020a) Hydro-mechanical properties of unsaturated residual soil from a flysch rock mass. *Eng Geol* 269:105546.

Peranić J, Arbanas Ž (2020) Impact of the wetting process on the hydro-mechanical behavior of unsaturated residual soil from flysch rock mass: preliminary results. *Bull Eng Geol Environ* 79:985–998.