Date of Submission	31 March 2025

IPL Project 256 Annual Report Form

Period of activity under report
from 1 January 2024 to 31 December 2024

1. **Project Number and Title: IPL-256, 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**

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   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, Associate Professor; martina.vivoda@gradri.uniri.hr

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

4. **Objectives** (5 lines maximum): Investigate the hydro-mechanical response of soils and slope models exposed to simulated rainfall using a newly developed platform for testing downscaled slope models under 1*g* conditions; Use of the experimental data together with numerical modeling to investigate the role of rainfall characteristics, hydro-mechanical soil properties, geometric and boundary conditions in landslide initiation by rainfall; Investigate the applicability of the adopted research methodology in defining rainfall thresholds.

5. **Study Area**: The research activities will be carried out in the Geotechnical laboratory of the Faculty of Civil Engineering, University of Rijeka.

6. **Project Duration**: 4 years

7. **Report**

1) Progress in the project: In the third year of the project, the research activities primarily focused on the hydromechanical characterization of soil materials used in model testing. Additionally, numerical modeling efforts have been continuously conducted to calibrate numerical models and investigate the stability conditions of physical slope models under tested rainfall loads. To enhance data quality, a soil-specific calibration of soil moisture content sensors was also performed. Most of these activities were carried out in collaboration with students enrolled in graduate (Slope Stability) and undergraduate (Introduction to Unsaturated Soil Mechanics) courses. Furthermore, the research contributed to the completion of four final theses and two master's theses defended in 2024, as detailed at the end of the report. A significant research collaboration was also established with Dr. Beena Ajmera from Iowa State University, an active member of the ICL. Together with her PhD candidate, coupled hydro-mechanical numerical modeling of slope model tests is being conducted, with the expectation that these findings will result in several high-quality publications. The project's activities and results have been continuously disseminated at key international and national conferences. Notably, the project leader presented findings through invited lectures at the 22nd International Symposium on Geo-disaster Reduction (Salerno, 2024) and the 6th Regional Symposium on Landslides in the Adriatic-Balkan Region (Belgrade, 2024). Additionally, abstracts have been submitted for the 21st International Conference on Soil Mechanics and Geotechnical Engineering (Vienna, 2026) and the European Conference on Unsaturated Soil (Lisbon, 2025), with full contributions currently in preparation to present results obtained through the IPL-256 project. Furthermore, the project leader has prepared two research proposals directly related to the project’s objectives. These proposals were submitted to competitive calls for research funding and are currently undergoing the evaluation phase. The aim of these proposals is to secure substantial funding to acquire additional research equipment for both laboratory and field investigations of slopes'

hydro-mechanical response, addressing complex soil-vegetation-atmosphere interactions. This funding would not only support the natural progression of the research beyond controlled laboratory conditions but also facilitate the recruitment of new research assistants, further enhancing project outcomes. Overall, the project's activities, research dissemination, and international collaborations contribute significantly not only to advancing scientific knowledge in this field but also to strengthening the research group's capacities and visibility. Additionally, these efforts lay the foundation for the establishment of strong research networks capable of submitting competitive proposals to some of the most competitive international funding opportunities.

2) Planned future activities or statement of completion of the Project: In the coming year, testing and data interpretation will focus on understanding the behavior of materials and slope models composed of fine-grained soils or soils that undergo volumetric changes in response to variations in soil moisture (i.e., soil suction). While initial tests on such materials have already been conducted, findings from the project highlight the need for experimental modifications. In particular, adjustments are being made to the rainfall simulator unit to enable the application of very low rainfall intensities (2–8 mm/h) with uniform distribution per square meter of the model. The funds for these modifications and improvements are ensured through the institutional fundings of research activities. The collected data will also be used to investigate the influence of hydraulic hysteresis on slope stability and the hydromechanical response of the material—an area that has not yet been explored within this project and one that requires greater attention in the study of rainfall-induced landslides in general. Additionally, a master's thesis is currently being conducted to examine the saturated and unsaturated shear strength of soil materials used in physical modeling. This research focuses on the shear behavior of soils across a wide range of confining pressures, from very low values representative of slope model tests within the project framework to prototype-scale stress conditions typical in engineering practice. The dissemination of results and collaboration with project partners will also continue, with a particular focus on submitting findings to select ICL publications in 2025.

3) Beneficiaries of Project for Science, Education and/or Society: From a scientific point of view, new knowledge is gained on the hydromechanical behavior of soils and slopes under different rainfall and boundary conditions and on how physical and numerical modelling can be used as research tools in the study of different phenomena related to rainfall infiltration, e.g. slope stability and hydraulic and mechanical characterization of soils. Observations on pore water pressure and soil moisture conditions, hydraulic hysteresis effects and other relevant phenomena are particularly useful in the study of rainfall-induced landslides. The data and findings on soil's shear behavior under a range of confining stresses, under saturated and partially-saturated conditions are also very valuable as these are rarely conducted on a scale and precision encountered withing this project. The knowledge gained and the better understanding of the

mechanisms and processes in slopes exposed to rainfall is beneficial not only for practitioners and scientists dealing with rainfall-induced landslides, but also for society and the population affected by rainfall-induced landslides in general. The results of the project are presented at conferences, workshops and symposia on the research topic, promoting collaboration and knowledge exchange with other groups, also increasing the visibility of the group. Finally, there is also a strong educational component, as students have the opportunity to participate in various activities within the project, through different undergraduate, graduate and postgraduate courses, as well as working on their final, master's or doctoral thesis.

4) Results: The results of the project were published or prepared for submission in several journal papers and presented (or accepted for presentation) at the conferences, as outlined below:
   - Crescenzo, L., Peranić, J., Arbanas, Ž. And Calvello, M. (2024) An approach to calibrate the unsaturated hydraulic properties of a soil through numerical modelling of a small-scale slope model exposed to rainfall. Acta Geotech. https://doi.org/10.1007/s11440-023-02170-2
   - Peranić, J., Vivoda Prodan, M., Škuflić, R., & Arbanas, Ž. (2024). Preliminary Experiences in Determining the Soil–Water Characteristic Curve of a Sandy Soil Using Physical Slope Modeling. Water, 16(13), 1859. https://doi.org/10.3390/w16131859
   - Peranić, J. and Arbanas. Ž. (2024) Hydraulic characterization of soil through physical slope modelling. 22nd International Symposium on Geo-disaster Reduction. Salerno, Italy, 22-25 July 2024. (Invited lecture).
   - Peranić, J. Vivoda Prodan, M., Čeh, N., Škuflić, R. and Arbanas, Ž. (2024) Determination of the soil-water characteristic curve of the soil by physical modelling tests. The 6th Regional Symposium on Landslides in the Adriatic-Balkan Region. Belgrade, Serbia, 15-18 May 2024. (Invited lecture).
   - Vivoda Prodan, M., Peranić, J., Jagodnik, V., Marušić D., Štiberc, D., Kamenar, N. and Arbanas, Ž. (2024) Shear strength of sand under different range of confining stresses using various shearing devices. XVIII European Conference on Soil Mechanics and Geotehnical Engineering. Lisbon, Portugal, 26-30 August 2024.

   Final and Master's Thesis Conducted as a part of the Project:
   - Alen Babajić: Calibration of the Soil Moisture Sensor for Interpreting the Results of the Physical Slope Model. Final thesis defended in July 2024 (Supervisor: Assist. Prof. Josip Peranić)
   - Leon Merleta: Numerical Parametric Analyses of Rainfall Infiltration into Soil Using a Numerical Model. Final thesis defended in September 2024 (Supervisor: Assist. Prof. Josip Peranić)
   - Luka Kocijančić: Investigation of the Influence of Simulated Rainfall Characteristics on the Development of Pore Pressures and Moisture in the Physical Slope Model. Final thesis defended in September 2024 (Supervisor: Assist. Prof. Josip Peranić)
   - Maja Krstinić: Analyses of Instability Development in a Scaled Physical Slope Model. Final thesis defended in September 2024 (Supervisor: Assist. Prof. Josip Peranić)
   - Marijan Pil: Analysis of Groundwater Level Development in a Scaled Landslide Model. Master's

thesis defended in September 2024 (Supervisors: Prof. Željko Arbanas and Assist. Prof. Josip Peranić)

- Monika Brajdić: "Analysis of Landslide Development in a Scaled Physical Model Induced by Rainfall. Master's thesis defended in September 2024 (Supervisors: Prof. Željko Arbanas and Assist. Prof. Josip Peranić)