Date of Submission	29 March 2024

IPL Project 256 Annual Report Form

Period of activity under report
from 1 January 2023 to 31 December 2023

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**

   Affiliation: University of Rijeka, Faculty of Civil Engineering; Assistant Professor

   Telephone: +385 51 265 943

   Email: 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, 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: Progress in the project: In the second year of the project, the activities for testing slope models under different boundary and rainfall conditions as well as the interpretation of the test results obtained were continued. Most of the activities were carried out in collaboration with students in graduate (Slope Stability) and undergraduate (Introduction to Unsaturated Soil Mechanics) courses, as well as in the context of final (1) and master theses (1), as described at the end of the document. The activities and results of the project are continuously disseminated at the main international and national conferences (4, including the 6th LWLF). As a result of the project activities, two original research papers have been published in international journals, one book chapter in ICL's OA book series "Progress in Landslide Research and Technology", while one journal paper and three papers for international conferences have been prepared for submission or accepted for presentation, respectively. The hydraulic and mechanical characterisation of the soils used for physical modelling is carried out continuously. The hydraulic characterisation of the pure sand - the material used in the first series of tests - was carried out numerically by inverse modelling of the experimentally obtained data following the approach recently proposed by Crescenzo et al. (2024), while other laboratory tests to determine the shear strength properties, water retention and hydraulic conductivity of soils are carried out as part of various activities. Based on the experience and results of the project, another research proposal was accepted for funding (uniri-iskusni-tehnic-23-240) and another research proposal is currently being written. These will enable future funding of the project activities and dissemination of the results. Finally, the experimental results are being used for numerical modelling, not only within the research group, but also through intensive collaboration with research groups from Italy (University of Salerno) and the USA (Iowa State University). The activities within the project, the dissemination of the results and the international collaboration within the project are therefore valuable not only from a scientific point of view for the topic

dealt with in the project, but also for improving the capacities and visibility of the research group.

2) Planned future activities or statement of completion of the Project: So far, the tests have focussed on uniformly grained fine sand. Depending on the availability of the platform and other resources, the focus of testing and data interpretation in the following year will be on understanding the behaviour of materials and slope models consisting of fine-grained soils or soils that generally experience a volumetric change with a change in soil moisture (i.e. soil suction). This will require some modifications to the approaches used and/or proposed so far and the coupling between hydraulic and mechanical responses under different rainfall conditions would be a particular challenge and moment of interest. The data collected will also be used to study the influence of hydraulic hysteresis on slope stability and the hydromechanical response of the material in general. Considering the duration of the tests and the specific loading conditions that must be taken into account, the hydromechanical characterisation of the soils used in the study will also be carried out continuously under relevant testing conditions. Dissemination of the results and collaboration with partners will also continue, with a focus on submission to some of the ICL's publications.

3) Beneficiaries of Project for Science, Education and/or Society: 3) Beneficiaries of the project for science, education and/or society: From a scientific point of view, new knowledge is gained on the hydromechanical behaviour 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 characterisation 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 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
   - Vivoda Prodan, M., Peranić, J., Pajalić, S. and Arbanas, Ž. (2023) Physical Modelling of

Rainfall-Induced Sandy and Clay-Like Slope Failures. Advances in Materials Science and Engineering, 2023, pp.1–12. https://doi.org/10.1155/2023/3234542.

- Arbanas, Ž., Peranić, J., Jagodnik, V., Vivoda Prodan, M., and Čeh, N. (2023) Remedial Measures Impact on Slope Stability and Landslide Occurrence in Small-Scale Slope Physical Model in 1 g Conditions. In: Alcántara-Ayala, I., et al. Progress in Landslide Research and Technology, Volume 2 Issue 2, 2023. Progress in Landslide Research and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-44296-4_9
- Peranić, J., Jagodnik, V., Vivoda Prodan, M. and Arbanas, Ž. (2023) Research on rainfall-infiltration induced landslides through physical and numerical modelling (In proc. of the 9th Conference of Croatian Geotechnical Society with international participation and under the auspices of ISSMGE: *Geotehnika u epicentru – Petrinja 2020*. Sisak, Croatia, 4-6 May 2023)
- Vivoda Prodan, M., Čeh, N., Peranić, J., Pajalić, S., Jagodnik, V. and Arbanas, Ž. (2023) Influence of pile wall on stability of clay-like slopes during rainfall in a small-scale physical modeling. Proc. of the 9th Conference of Croatian Geotechnical Society with international participation and under the auspices of ISSMGE: *Geotehnika u epicentru – Petrinja 2020*. Sisak, Croatia, 4-6 May 2023.
- Peranić, J., Crescenzo, L., Calvello, M., Arbanas, Ž. (2023) Investigation of the hydraulic response and stability conditions of a small-scale sandy slope. The second Mediterranean Symposium on Landslides. Hammamet, Tunisia, 5-7 October 2023.
- Peranić, J., Vivoda Prodan, M., Jagodnik, V., Čeh, N., Arbanas, Ž. (2023) Investigating the hydraulic response of a slope model under different rainfall conditions through physical modelling. 6th World Landslide Forum. Florence, Italy, 14-17 November 2023.
- 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).
- Arbanas, Ž., Peranić, J. and Mihalić Arbanas, S. (2024) Analysis of an old rock avalanche using different remote sensing methods. ISRM European Rock Mechanics Symposium - EUROCK 2024. Alicante, Spain, 15-19 July 2024 (Accepted for oral presentation).
- Vivoda Prodan, M., Peranić, J., Jagodnik, V., Marušić D., Štiberc, D., Kamenar, N. and Arbanas, Ž. (in press) Shear strength of sand under different range of confining stresses using various shearing devices. XVIII European Conference on Soil Mechanics and Geotehnical Engineering. Lisabon, Portugal, 25-30 August 2024 (Paper accepted for oral presentation).

Final and Master's Thesis Conducted as a part of the Project:

- Dora Štribec: Determination of the shear strength parameters of sand with a direct shear apparatus. Final thesis defended in July 2023 (Supervisor: Josip Peranić, PhD)
- Rea Škuflić: Hydraulic response of a physical slope model under different rainfall intensities. Master's thesis defined in September 2023 (Supervisors: Prof. Željko Arbanas, PhD and Josip Peranić, PhD)