Date of Submission	

IPL Project (IPL - 269) Annual Report Form 2025

1 January 2025 to 31 December 2025

1. **IPL – 269 (2023) Landslide Initiation, Evolution and Remediation: Physical and Numerical Modeling (LIEREM)**

2. **Main Project Fields**

(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:** Professor Željko Arbanas

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Core members of the Project:

Sabatino Cuomo/ University of Salerno, Department of Civil Engineering, Associate Professor; scuomo@unisa.it

Josip Peranić/ University of Rijeka, Faculty of Civil Engineering, Postdoc; josip.peranic@gradri.uniri.hr

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4. **Objectives:** Investigation of rainfall-induced landslides by combining 1g small-scale physical landslide models and advanced numerical modelling approaches; investigation of landslide initiation and propagation stages; evaluation of the effectiveness of different remediation measures such as gravity walls, piles and gabions for different slope materials and geometric conditions.

5. **Study Area:** The research activities are carried out in the Geotechnical laboratory of the Faculty of Civil Engineering, University of Rijeka and in the Geotechnical Laboratory of the Department of Civil Engineering, University of Salerno. The results will be applicable to the research topic in general.

6. **Project Duration:** 4 years

7. **Report**

Progress in the Project:

During the second year of the Project, the activities from the following phases of the Project were conducted:

1st phase: PHYSICAL SMALL-SCALE LANDSLIDE MODELLING

Conducting 1g physical model tests of small-scale landslides with different soil types, geometric and initial moisture conditions, predefined rainfall conditions and installation of some remedial structures: PHYSICAL SMALL-SCALE LANDSLIDE MODELLING; Milestone: Obtained some of data on the hydraulic and mechanical behavior of small-scale landslides under specified test conditions. This phase will be continued in the next years of the research.

2nd phase: DATA ANALYSIS

Analysis of data collected in phase 1, including changes in soil moisture, pore water pressure (positive and matric suction), temperature and landslide/structure movement data: DATA ANALYSIS; Milestone: Analysis and interpretation of data collected from investigation in phase 1. Data Analysis is a continued research based on physical small-scale landslide modeling data. The results of investigating the effect of rainfall patterns on slope stability through physical and numerical modelling, pointed on the rainfall patterns affect hydraulic behavior and slope stability (Peranić et al., 2026). Prediction of hydro-mechanical slope response and landslide initiation based on a slope physical model exposed to artificial rainfall used FEM numerical simulation to numerically simulate the process in a slope to landslide initiation (Roy et al., 2026a, b). This phase will be continued in the next years of the research.

3rd phase: SOIL TESTING.

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. Conducted data analyses were Soil Testing is continued research during the Project period.

4th phase: NUMERICAL MODELLING

Use the obtained data to perform advanced numerical analyses (MPM) of rainfall infiltration, landslide evolution from triggering to final deposition and even landslide-structure interaction: NUMERICAL MODELLING; Milestone: Use the data obtained in phases 2 and 3 to calibrate numerical models and perform various numerical studies and parametric analyses and to assess the performance of different remediation measures. Numerical modelling using the Material Point Method (MPM) was used in analyses of possible debris flows remediation measures using long-rooted grass or different rigid and flexible structures. Cuomo et al. (2025) analyzed the behavior of rigid barriers impacted by multiple surges of flow-like landslides. The MPM is used for its capability to accommodate large deformation scenarios, with distinct material properties, while still recurring to classical concepts of geotechnical engineering implemented in traditional Finite Element Method (FEM) approaches. The results show that multiple surges lead to a more gradual dissipation of kinetic energy compared to a single, larger flow of equivalent mass. This phase will be continued in the next years of the research.

8) Planned future activities or Statement of completion of the Project

The future activities will develop according to the Project Work Plan. In the next Project year, the following activities will be continued:

1st phase: PHYSICAL SMALL-SCALE LANDSLIDE MODELLING

This phase will be continued in the next years of the research.

2nd phase: DATA ANALYSIS

Data Analysis is a continued research based on physical small-scale landslide modeling data.

3rd phase: SOIL TESTING.

Soil Testing is a continued research during the Project period.

4th phase: NUMERICAL MODELLING

This phase will be continued in the next years of the research.

9) Beneficiaries of Project for Science, Education, and/or Society

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, mitigation measures, and triggering mechanisms of landslides initiated by rainfall in general; Institutions and working groups involved in the project through knowledge sharing, increasing their visibility and capacity. As the project is still ongoing, further developments of research in physical and numerical landslide modeling are widely expected. Already, current results within the project area certainly significantly contribute to a better understanding of landslide initiation and behavior, both for scientists and the engineering profession.

10) Results:

- 1. Peranić, J., Vivoda Prodan, M., Čeh, N., Škuflić, R., Arbanas, Ž. Determination of the Soil-Water Characteristic Curve of the Soil by Physical Modelling Tests. Proceedings of the 6th Regional Symposium on Landslides in the Adriatic-Balkan Region, ReSyLAB2024, Belgrade, Serbia 15–18th May 2024 / [ed. Miloš Marjanović, Uroš Đurić]. - ISBN 978-86-7352-402-3. - Vol. 6 (2024), p. 73–80.

- 2. Crescenzo, L., Peranić, J., Arbanas, Ž. et al. 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. 19, 4437–4456 (2024). https://doi.org/10.1007/s11440-023-02170-2

- 3 Cuomo, S., Di Perna, A., Moscariello, M. et al. Possible remediation of impact-loading debris avalanches via fine long rooted grass: an experimental and material point method (MPM) analysis. Landslides 21, 679–696 (2024). https://doi.org/10.1007/s10346-023-02178-5

- 4. Di Perna, A., Cuomo, S., Martinelli, M. (2023). Modelling of Landslide-Structure Interaction (LSI) Through Material Point Method (MPM). In: Alcántara-Ayala, I., et al. Progress in Landslide Research and Technology,

Volume 2 Issue 1, 2023. Progress in Landslide Research and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-39012-8_6

- 5 Sabatino Cuomo, Angela Di Perna, Mario Martinelli, Charles W.W. Ng, Weerakonda Arachchige Roanga K. De Silva, Clarence E. Choi, Class A prediction of debris flow impact forces on dual rigid and flexible barriers: MPM modelling, Computers and Geotechnics, Volume 173, 2024, 106556
- 6. Peranić, J., Leonard, A., Kocijančić, L., Arbanas, Ž. (2026) Investigating the effect of rainfall patterns on slope stability through physical and numerical modelling. In: Boldrin, D., Cecconi, M., Cotecchia, F., Leung, A., Pedone, G., Perrini, P., Romero, E., Tagarelli, V., Zdravković, L. (eds), Proceedings of the 3rd International Workshop on Soil-Vegetation-Atmosphere Interaction (RootS25). https://doi.org/10.53243/RootS2025-55
- 7. Roy, R., Ajmera, B., Peranić, J., Arbanas, Ž. (2026a) 'Forward Prediction of Hydro-Mechanical Slope Response under Rainfall'. Landslides (under review).
- 8. Roy, R., Ajmera, B., Arbanas, Ž., Peranić, J. (2026b) Predictions of Slope Performance during Rainfall Using Numerical Analysis. In: Proceedings of the 21st International Conference on Soil Mechanics and Geotechnical Engineering, Vienna (in press).