Date of Submission	15 September 2022

IPL Project Proposal Form 2023

1. Project Title: **Landslide Initiation, Evolution and Remediation: Physical and Numerical Modeling (LIEREM)**
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: **Željko Arbanas, Full Professor**

Affiliation: University of Rijeka, Faculty of Civil Engineering, Head of Geotechnical Chair

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

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

Angela Di Perna/ University of Salerno, Department of Civil Engineering, Postdoc; adiperna@unisa.it

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. Background Justification: Understanding the physical processes and mechanisms that drive the instability phenomena of rainfall-induced landslides remains an important topic for landslide science. Modelling these phenomena is difficult due to the complex processes and numerous variables involved in both the pre- and post-failure phases of landslides. These include highly nonlinear material property functions, stress- and strain-dependent soil behavior, interactions between solid particles and pore fluid, quantification of time-dependent boundary conditions, hydraulic soil hysteresis effects, complex soil

profile conditions and others. Small-scale physical landslide models, in combination with appropriate sensor networks and monitoring techniques, allow accurate observation of the hydraulic and mechanical response of slope models under precisely controlled test conditions. This makes them a valuable tool for the accurate measurement of quantities and variables controlling instability phenomena. They are particularly useful in combination with advanced numerical modelling techniques, where the numerical modelling, once properly calibrated against the high quality experimental data, can also be used for a more detailed investigation of the observed phenomena, as well as to overcome limitations typically inherent to physical models, such as spatial and temporal constraints, barotropy-related effects, etc. The Material Point Method (MPM) is one of the recently developed numerical approaches that has the potential to reproduce most of the complex processes mentioned previously, including fully coupled hydro-mechanical modelling for large deformations. This is of great help in correctly simulating the complex failure and post-failure mechanisms of rainfall-induced landslides, but it can also be particularly useful in evaluating the interaction forces or deformations on the remediation measures and assessing their effectiveness in general.

6. Study Area: The research activities will be 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.
7. Project Duration: 4 years
8. Resources necessary for the Project and their mobilization
   Personnel: Two (2) senior researchers, three (3) 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 (Plaxis 2D, Anura3D); Budget: 70,000 USD.
9. Project Description: The main idea of the project is to use some of the results of small-scale physical landslide models tested under 1g rainfall infiltration conditions, using different soil types, geometric and test conditions, with and without remediation measures applied, to investigate the hydromechanical response of slope models under different rainfall conditions and to test the applicability of some remediation structures to mitigate the landslide effects. The study will rely on data obtained from physical model tests and advanced numerical modelling techniques that allow a more detailed investigation of the hydromechanical response of slope models both in the pre- and post-failure phases. Numerical models, especially fully coupled hydro-mechanical large-deformation models, are of great help in correctly simulating the complex failure and post-failure mechanisms of rainfall-induced landslides. Indeed, the affected soils evolve from no or low deformation rates to large deformation rates during the initiation phase and vice versa during the deposition phase, with relevant interactions between the solid skeleton and the interstitial water. The Material Point Method (MPM) has the potential to fully reproduce these complex processes. The results of the proposal will be submitted for publication in relevant journals, such as the Landslides journal or the ICL Open access book series.
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, predefined rainfall conditions and installation of some remedial structures: PHYSICAL SMALL-SCALE LANDSLIDE MODELING; Milestone: Obtain data on the hydraulic and mechanical behavior of small-scale landslides under specified test conditions.

2nd phase: 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 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 (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.

11. Deliverables/Time Frame:

    1st phase: 1g physical model tests conducted for different test conditions and remediation measures. Time duration: within the first two years of the project.

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

    3rd phase: Laboratory testing for advanced hydro-mechanical soil characterization. Time duration: during the third and fourth year of the project.

    4th phase: Numerical analyses to investigate the hydro-mechanical response of slopes under test conditions and for different stages of landslide activity, as well as for the assessment of the effectiveness of different remediation measures. 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, mitigation measures and triggering mechanisms of landslides initiated by rainfall in general; Institutions and working groups involved in the project through knowledge shearing, increasing their visibility and capacity.

13. References:

- Cuomo, S., Perna, A. D., & Martinelli, M. (2021). Material point method (MPM) hydro-mechanical modelling of flows impacting rigid walls. *Canadian Geotechnical Journal*, 58(11), 1730-1743.

- Cuomo, S., Di Perna, A., & Martinelli, M. (2021). Modelling the spatio-temporal evolution of a rainfall-induced retrogressive landslide in an unsaturated slope. *Engineering Geology*, 294, 106371.
- Cuomo, S., Di Perna, A., & Martinelli, M. (2022). Analytical and numerical models of debris flow impact. *Engineering Geology*, 308, 106818.
- Peranić, J., Arbanas, Ž. (2022) The influence of the rainfall data temporal resolution on the results of numerical modelling of landslide reactivation in flysch slope. *Landslides*. https://doi.org/10.1007/s10346-022-01937-0
- 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
- Peranić, J., Moscariello, M., Cuomo, S., Arbanas, Ž. (2020). Hydro-mechanical properties of unsaturated residual soil from a flysch rock mass. *Eng Geol* 269:105546.