Date of Submission	December 19 -2022

IPL Project Proposal Form 2022

(MAXIMUM: 3 PAGES IN LENGTH)

1. **Project Title:** (2 lines maximum) Slope monitoring of San Eduardo landslide in Colombia using multiple techniques
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
3. **Name of Project leader**: Guillermo Ávila

Affiliation: (office and position): Associate Professor at National University of Colombia, Building 406 – office 208. Contact: (postal address, fax, phone, email) geavilaa@unal.edu.co

Core members of the Project: Names/Affiliations: (4 individuals maximum):

- Carlos Eduardo Rodríguez Pineda, Assocate Professor at National University of Colombia.
- Julio Guerra, PhD student in Civil Engineering at National University of Colombia

4. **Objectives**: (5 lines maximum; what you expect to accomplish?)

- Comparing multiple monitoring techniques for large slope movements
- Stablishing the conditional and triggering factors of the San Eduardo Landslide in Colombia
- Modelling large displacements of the landslide using Material Point Method and validate the numerical results with the current instrumentation and multiple remote sensing technics.
- Identifying the key elements for early warning systems in large area landslides.

5. **Background Justification: (10 lines maximum)**

Although landslides with large areas (>0,1 km2) have a low spatial and temporal recurrence (Malamud et al., 2004), their effects can exceed the response capabilities of population. Nowadays the occurrence mechanism, travel distances, velocities, and behavior of landslide after the rupture are poor understanded (Cecinato et al., 2011). Also, the numerical technics based on mesh, such as Finite Elements (FEM) or Finite Differences (FDM) due the high distortion of the mesh are no suitable to modeling large deformations as occurs in large landslides. The methods based on particles, for instance, Material Point Method (MPM) can deal with large deformations thanks to lagrangian-eulerian approach (Tjung & Soga, 2020; Alonso et al., 2014; Soga et al., 2016; Troncone et al., 2020). These type of events in Colombia tend to be related with colluvial deposits on shales, and most of them have been triggered by extreme rains and can be reactivated in the medium or long term.

In September 2018 a very large landslide occurred in a rural area of the Boyacá department (Colombia) affecting 411 Ha, mobilizing about 53.200.000 m^3 of colluvial materials. According to its volume (>1.000.000 m^3) the San Eduardo landslide can be considered as a large landslide (Corominas, 2011; Fell et al., 2005). The travel distances were from some cm to more than 100 m, affecting 18 km of roads, farmlands and houses. The post event area was instrumented with 6 piezometers, 6 inclinometers and a very extensive geotechnical survey and laboratory test were conducted by the Colombian Geological Service. This landslide permits to evaluate and compare different monitoring techniques including direct and remote monitoring to develop a robust early warning system.

6. **Study Area:** Municipality of San Eduardo (Boyacá, Colombia)
7. **Project Duration:** 3 years
8. **Resources necessary for the Project and their mobilization (Personnel, Facilities, and Budgets)**

Leader project: Guillermo Ávila, Civil Engineer, PhD; Associate professor at Department of Civil Engineering and Agricultural (Bogotá), National University of Colombia

Researcher: Julio César Guerra, Geologist, MSc, PhD student in Civil Engineering at National University of Colombia. Lecturer at Department of Civil Engineering and Agricultural (Bogotá), National University of Colombia

Adviser: Carlos Eduardo Rodríguez, Civil Engineering, PhD. Associate professor at Department of Civil Engineering and Agricultural (Bogotá), National University of Colombia

External Researchers: We will look for the collaboration of ICL Members working on landslide monitoring

Facilities and resources: The project count with the geotechnical laboratory from National University of Colombia. In the site of landslide there are installed 6 piezometers and 6 inclinometers, with data from 2018, also 300 m of drilling distributed in 20 rotatory drillings and 10 trenches with core and sample recovery respectively which have laboratory testing. Field and laboratory works will be financed by the University Budget.

9. **Project Description: (30 lines maximum)**

The aim of this project is to explore alternative technics for slope monitoring such as differential interferometric images (InSAR), particle image velocimetry from unmanned aerial vehicle, and the use of optic fiber to measure slope deformations. After the event in September 2018, the slope was instrumented by the Colombian Geological Service with 6 piezometer and 6 inclinometers; Also, an extensive laboratory testing of different surface materials (up to 20 m depth). Although there are meaningful data and the landslide is still active, the evaluation of triggering mechanisms and post failure behavior require much more work, in order to understand the real failure parameters and the displacements conditions of such as large mass.

With the data gathered with the current instrumentation and techniques described above, we will compare rain and deformation data to calibrate the activity parameter of landslide, focusing on stablishing an early warning system. In this project, we will also develop a physical model to scale, for testing the use of optic fiber to measure continuous deformations and tilting. In the frame of the project, we will also conduct new field work, and numerical modelling using the Material Point Method (MPM) to reconstruct the behavior of landslide during and after the rupture, establishing the causal and triggering factors for the Sand Eduardo Landslide. The results of this work can represent an advantage of knowledge on large landslides, especially on colluvial deposits that are very common in tropical regions.

10. Work Plan/Expected Results: (20 lines maximum; work phases and milestones)

Phase	**Description / Expected Results**	**First year**		**Second year**		**Third year**	
		2023-1	**2023-2**	**2024-1**	**2024-2**	**2025-1**	**2025-2**
1	Extended bibliography review / Conceptual frame						
2	Get all available data of instrumentation, geotechnical survey, rain data, and lab testing developed by Colombian Geological Service / Available data input						
3	Check the state of instruments in field and field work / Identification of materials, physical conditions of slope, and fly UAV to get images of landslide.						
4	Build the physical model to test the use of optic fiber / First implementation of technic at small scale						
5	Get and analyze the differential interferometric images / remote sensing image input						
6	Install on field the optic fiber to monitoring the slope deformation / Implementation of technic on terrain						
7	Processing the remote sensing images and optic fiber data to evaluate the slope deformations / Identify the slope and landslide activity						
8	Model the run-out of landslide with the MPM / Reconstruction of terrain model before and after of landslide, and an estimation of variables of movement of landslide.						
9	Analyze and compare the measurements from new and former instrumentation / Identify the differences and issues of sensors, data and performance of monitoring technics implemented. Formulate an early warning system based on the collected data.						
10	Writing report and scientific article with results						

11. Deliverables/Time Frame: (10 lines maximum; what and when will you produce?)

- A landslide deformation model based on the rain data, geotechnical conditions, and the monitoring information (Third year).
- Update the data base of large landslides with San Eduardo event (First year).
- A proposal for the implementation of an early warning system on-site based on multiple technics (Third year).
- Three published articles: ICL Open access book series with the results of the project and Landslide journal (end of each year during 3 years).

12. Project Beneficiaries: (5 lines maximum; who directly benefits from the work?)

- Direct benegiciaries will be the community near to slope in San Eduardo, department of Boyacá, Colombia (163 people) composed by 60 farmer families.
- The National System of Disaster Risk Management due improvement in the knowledge of initial signs of large landslide processes in colluvial Colombian deposits and the proposal of and early warning system with multiple monitoring technics.
- The academic community considering the new insights on large landslides on colluvial deposits, especially its behavior during and post failure event. That includes the National University with a strengthening in research network of the of Civil Engineering Department.

13. References (Optional): (6 lines maximum; i.e. relevant publications)

Alonso, E. E., Pinyol, N. M., & Yerro, A. (2014). Mathematical Modelling of Slopes. *Procedia Earth and Planetary Science*, *9*, 64-73. https://doi.org/10.1016/j.proeps.2014.06.002

Cecinato, F., Zervos, A., & Veveakis, E. (2011). A thermo-mechanical model for the catastrophic collapse of large landslides. *International Journal for Numerical and Analytical Methods in Geomechanics*, *35*(14), 1507-1535. https://doi.org/10.1002/nag.963

Corominas, J. (2011). The angle of reach as a mobility index for small and large landslides. *Canadian Geotechnical Journal*. https://doi.org/10.1139/t96-005

Fell, R., Ho, K. K. S., Lacasse, S., & Leroi, E. (2005). *A framework for landslide risk assessment and management*. 3-25.

Malamud, B. D., Turcotte, D. L., Guzzetti, F., & Reichenbach, P. (2004). Landslide inventories and their statistical properties. *Earth Surface Processes and Landforms*, *29*(6), 687-711. https://doi.org/10.1002/esp.1064

Soga, K., Alonso, E., Yerro, A., Kumar, K., & Bandara, S. (2016). Trends in large-deformation analysis of landslide mass movements with particular emphasis on the material point method. *Géotechnique*, *66*(3), 248-273. https://doi.org/10.1680/jgeot.15.LM.005

Tjung, E. Y. S., & Soga, K. (2020). *Liquefaction-Induced Dam Failure Simulation—A Case for the Material Point Method*. 2020 Annual Scientific Meeting of Indonesian Society For Geotechnical Engineering. https://doi.org/10.48550/arXiv.2111.13584

Troncone, A., Pugliese, L., & Conte, E. (2020). Run-Out Simulation of a Landslide Triggered by an Increase in the Groundwater Level Using the Material Point Method. *Water*, *12*(10), Art. 10. https://doi.org/10.3390/w12102817

Note: Please fill and submit this form by 15 September 2022 to ICL Network <icl-network@iclhq.org> and KLC secretariat <klc2020@iclhq.org>