

Application Form for World Centre of Excellence on Landslide Risk Reduction
2023-2026

1. Name of Organization: Croatian Landslide Group

2. Name of Leader

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Core members of the activities (4 individuals maximum)

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Assist. Prof. Petra Jagodnik, University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia

3. Date of Submission of Application: 30 March 2023

4. Activity scale and targeted region.

1) **Global**, 2) Intercontinental, 3) Continental, 4) **Regional**, 5) **National**

5. Short Title characterizing past and planned activities (10 words maximum)

Croatian Center for Applied Landslide Research

6. Objectives for 3 years:

(i) Further development of scientific methods related to landslide identification, mapping, susceptibility, hazard and risk analysis, modeling and zonation with the application to landslide types characteristic for the Pannonian Basin and the Dinarides (Dinaric Alps); (ii) Physical modelling of landslide initiation and landslide remediation constructions behavior under static and seismic actions, and physical and numerical

modeling of landslide initiation caused by rainfall infiltration; (iii) Modeling of rockfalls and protection of rockfall endangered areas; (iv) Landslide monitoring, prediction and development of early warning systems; (v) Promotion of landslide research and science for regional, national and local application and support action by local communities and authorities.

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

The members of the Croatian Landslide Group (CLG) are the landslide scientists in the fields of engineering geology and civil engineering employed at the University of Rijeka and the University of Zagreb. The CLG members are involved in a wide spectrum of activities related to landslide risk reduction, from high education and scientific research to cooperation with industry, as well as with local and national authorities. The results of the joint scientific research of CLG scientists (2010-2023) are published in PhD dissertations, international journals papers (including Landslides journal) and in international conferences papers, as well as in chapters in ICL Open Access Book Series “Progress in Landslide Research and Technology”. The regional scientific and high-education projects and cooperation are the following: two national scientific projects funded by the Croatian Scientific Foundation; mobility of lecturer, researcher and students between Croatia and Italy; co-ordination of regional ICL Adriatic-Balkan network; organisation of a regional symposium on landslides (1st ReSyLAB in Zagreb in 2013 and 5th ReSyLAB in Rijeka, Croatia in 2022) and WLF5 (Kyoto, Japan, 2021). CLG has continuous cooperation with Croatian local, regional and national governments and agencies; consultative support to authorities related to landslides investigation and urgent situations; design of landslides remedial measures, presentation of the application of scientific results in praxis (e.g., landslide inventories, landslide hazard and risk zonation and mapping, landslide monitoring, prediction and early warning); and involvement in joint activities related to ICL (e.g., Sendai Partnership, editing of ICL Open Access Book Series “Progress in Landslide Research and Technology” and the Landslides Journal).

8. **Resources available for WCoE activities Personnel, Facilities, Budgets, and Affiliation and Contribution to ICL/IPL and KLC2020:**

CLG encompasses two university departments from the University of Rijeka and the University of Zagreb (Department for Geology and Geological Engineering) with 2 Full Professors, 1 Associate Professor, 3 Assistant Professors, 1 Postdoctoral researcher and 3 PhD students. The key infrastructures for scientific research are: Geotechnical Laboratory at the Faculty of Civil Engineering University of Rijeka equipped with modern equipment for soil and rock testing (triaxial and dynamic triaxial apparatus, undrained ring shear apparatus, resonant column, triaxial apparatus for rock testing, direct shear),

Observatory of the Kostanjek Landslide at the University of Zagreb equipped with integrated automated monitoring systems. High-educational activities are fully supported by the faculties. Funds for scientific research are ensured through national scientific projects, international multilateral and bilateral projects as well as cooperation with industry.

CLG has been involved in the following ICL/IPL activities: leading six IPL projects (IPL-173, IPL-184, IPL-219, IPL-220, IPL-256 and IPL-257); editing and reviewing in the Landslide journal; editing and contributing to the ICL Open Access Book Series “Progress in Landslide Research and Technology” (2 chapters in Vol. 1; 3 chapters in Vol. 2); contributing to the organisation of WLF5 in Kyoto, Japan and WLF6 in Florence, Italy, as well as theme editors for two books of WLF Proceedings; and organising 1st and 5th Regional ICL Symposium on Landslides in Adriatic Balkan Region (Zagreb, 2013 and Rijeka, 2022).

9. Description of your past activities related to risk reduction of landslides and other related earth system disasters (30 lines maximum)

Scientific activities related to the risk reduction of landslides through development and/or applications of landslide science were as follows:

- Application of innovative (visual interpretation of high- and very high-resolution DEMs) landslide identification and mapping methodologies for the purpose of identification of shallow landslides formed in soils in the hilly areas of the European Pannonian Basin; various landslide types associated with erosion processes in complex geological environments in flysch areas in the wider zone of Adriatic Coast of Croatia (the Vinodol Valley). Identification of landslide triggers on the basis of compilation of a catalog of precipitation events that have caused landslides in the NW Croatia (NW part of Pannonian Basin) covering the period between June 2006 and March 2023.
- Landslide characterization aimed at interpretation of landslide model for the purpose of design of remedial measures in Croatia using: (a) surface and subsurface investigation of landslides (deep-seated Špičunak landslide and more than 20 shallow landslides endangering roads and residential houses); (b) surface investigation of rock falls/topples using airborne (ALS) and terrestrial laser scanning (TLS) as well as structure from motion (SfM) digital photogrammetry taken from unmanned aerial vehicle (UAV) that endanger sites of cultural heritages (Momjan Castle, City of Omiš), as well as roads (e.g. the Špičunak Rockfall near Delnice) and railways (e.g. the Raspadalica Rockfall near the City of Buzet).
- Laboratory testing of soft rocks-hard soils (flysch) materials with determination of parameters that allow the prediction of a material’s strength, deformation, or permeability in response to changes over time due to weathering process, stress or other environmental conditions (climate change). Application

of the described research results are demonstrated by use in numerical simulations of behavior landslides in flysch rock mass (e.g., the Valići landslide). Laboratory research of water infiltration in soil and impact of unsaturated zone of slope cross-section on overall slope stability and triggering of deep-seated landslides in flysch deposits. Application of the described research results are used in numerical simulations of initiation of deep-seated landslides in flysch rock mass.

- Landslide monitoring by integrated automated monitoring systems, the deep-seated large Kostanjek landslide. Analysis of temporal data series of movement and groundwater level data captured by the Kostanjek landslide monitoring system and development of a methodology for prediction of deep-seated slow moving landslide displacements using phenomenological modeling.
- Physical landslide modeling in static (rain induced landslides) and seismic (earthquake induced landslides) condition at 1g. Physical Modeling and analyses of landslide remediation construction behavior in static and seismic conditions at 1g. Construction of physical model and sensor system for monitoring of landslide initiation and development in small scale landslide models at 1g. Implementation of similarity laws in small scale physical modelling of real landslide processes.
- Assessment of landslide hazard and risk in Croatia and contribution in creating of strategic plan of risk management in Croatia: Assessment of Disaster Risks in Republic of Croatia. Contribution to Croatian National Platform for Disaster Risk Reduction.
- Enhancement of landslide science in the Adriatic-Balkan Region through the leading of ICL Adriatic Balkan Network activities, organization of 5th Regional ICL Symposium on Landslides in Adriatic Balkan Region (Rijeka, Croatia, 2022).
- Promotion of landslide research and science for regional, national and local applications and support in the system civil protection system, land use and adoption to climate changes through development of landslide inventories, landslide hazard and risk maps, as well as strategic documents and policies which are necessary for landslide risk management.

10. Planned future activities /Expected Results: (20 lines maximum; work phases and milestones)

Planned scientific activities related to landslides risk reduction in the period 2023-2026 are as follows:

- Further development of scientific methods related to landslide identification, mapping, susceptibility, hazard and risk analysis, modelling and zonation with the application to landslide types characteristic for the Pannonian Basin and the Dinarides (Dinaric Alps);
- Further research using landslide physical model to study remediation constructions behaviour under static and seismic actions based on current research results. The research will encompass testing of the behaviour of different construction applied for landslide remediation in physical models of scaled

landslides in static and dynamic conditions. Observations of landslide movements in a physical model will be carried out by novel sensor network for measuring displacements, pressures, forces and positive and negative pore pressures and innovative photogrammetric equipment including a terrestrial laser scanner and infrared camera. The measured parameters from physical model will be included in 3D numerical simulation. The results of both physical and numerical modelling will enable better understanding of landslide remedial construction behavior.

- Further development of landslide displacement phenomenological models as a tool for landslide early warning systems. The model will be developed based on series of measured monitored data on established landslide monitoring system (the Kostanjek Landslide) and will be verified on other deep-seated slow-moving landslides with existing monitoring data.
- Physical and numerical modeling of landslide initiation caused by rainfall infiltration will include measurement of surface water infiltration in physical landslide model and in situ as well as belonging pore pressure and matric suction values. Physical modeling data will ensure adequate numerical modelling and assessment of unsaturated zone impact on stability and initiation of deep-seated landslides.
- Field and numerical analyses of rockfalls and rock avalanches along the Adriatic coast of Croatia using remote sensing data (UAV LiDAR, photogrammetry and thermography techniques) for in field observations. The observed data and numerical analyses will be a base for prediction or rock cliff behavior in change climate conditions and establishment of systematic approach in in rockfall protection.
- Spatial analyses of massive landslides during historical rainfall events in Croatia will enable modeling of landslide activation under different rainfall thresholds that will use as a base for landslide hazard and risk maps in Croatia as well as for establishing of early warning systems in areas endangered by shallow landslides.
- Promotion of landslide research and science for regional, national and local applications and support in the system civil protection system, land use and adoption to climate changes through development of landslide inventories, landslide hazard and risk maps, as well as strategic documents and policies which are necessary for landslide risk management.

11. Beneficiaries of WCoE: (5 lines maximum; who directly benefits from the work?)

Society, through implementations of new advances in landslide science. National, regional and local authorities, through the development of landslide hazard and risk maps and strategic documents that are necessary for landslide risk management in the civil protection system, land use and adoption to climate changes. Governmental agencies and industry, through the implementation of new technologies and knowledge. Academic society, scientists, and professionals, through new scientific knowledge transfer.

12. References: 10 lines maximum, i.e., relevant publications, international/regional/national recognition supporting items 9-10.

- Bernat Gazibara, Sanja; Krkač, Martin; Mihalić Arbanas, Snježana. Landslide inventory mapping using LiDAR data in the City of Zagreb (Croatia) // *Journal of Maps*, 15 (2019), 2; 773-779 doi:10.1080/17445647.2019.1671906
- Josip Peranić, Tjeljko Arbanas. Impact of the wetting process on the hydro-mechanical behavior of unsaturated residual soil from flysch rock mass: preliminary results. *Bulletin of Engineering Geology and the Environment*, 2020, 79, 985–998
- Martin Krkač, Sanja Bernat Gazibara, Tjeljko Arbanas, Marin Sečanj, Snježana Mihalić Arbanas. A comparative study of random forests and multiple linear regression in the prediction of landslide velocity. *Landslides*, 17 (2020), 11; 2515-2531
- Petra Jagodnik, Sanja Bernat Gazibara, Tjeljko Arbanas, Snježana Mihalić Arbanas. Engineering geological mapping using airborne LiDAR datasets – an example from the Vinodol Valley, Croatia. *Journal of Maps*, 16 (2020), 2; 856-867
- Josip Peranić, Mariagiovanna Moscariello, Sabatino Cuomo, Tjeljko Arbanas. Hydro-mechanical properties of unsaturated residual soil from a flysch rock mass. *Engineering Geology*, 2020, 269, 105546
- Sara Pajalić, Josip Peranić, Sandra Maksimović, Nina Čeh, Vedran Jagodnik, Tjeljko Arbanas. Monitoring and Data Analysis in Small-Scale Landslide Physical Model. *Applied Sciences.*, 2021, 11(11): 5040
- Josip Peranić, Snježana Mihalić Arbanas, Tjeljko Arbanas. Importance of the unsaturated zone in landslide reactivation on flysch slopes: observations from Valići Landslide, Croatia. *Landslides*, 2021, 18: 2727-3751
- Sinčić, Marko; Bernat Gazibara, Sanja; Krkač, Martin; Lukačić, Hrvoje; Mihalić Arbanas, Snježana. The Use of High-Resolution Remote Sensing Data in Preparation of Input Data for Large-Scale Landslide Hazard Assessments // *Land (Basel)*, 11 (2022), 8; 1360, 37 doi:10.3390/land11081360
- Josip Peranić, Tjeljko Arbanas. The influence of the rainfall data temporal resolution on the results of numerical modelling of landslide reactivation in flysch slope. *Landslides*, 2022, 19: 1-14
- Sanja Bernat Gazibara, Marko Sinčić, Martin Krkač, Hrvoje Lukačić, Snježana Mihalić Arbanas. Landslide susceptibility assessment on a large scale in the Podsljeme area, City of Zagreb (Croatia). *Journal of Maps*, 19 (2023), 1, 11

13. If your organization is an ongoing WCoE 2020-2023, please attach the articles as pdf files reporting activities of WCoE, IPL project and ICL network published/contributed or a list of planned reports of WCOE 2020-2023 to either journal “Landslides” or/and “P-LRT books.”

The ongoing CLG WCoE 2020-2023 presented their achievements in 19 papers in international journals (including 3 papers in the Landslides journal) and 21 papers at the international conferences (including 4 papers at WLF5 in Kyoto), as well as 2 chapters in ICL Open Access Book Series “Progress in Landslide Research and Technology” Vol.1 Issue No.2. All these papers presented scientific results that are parts of activity of CLG WCoE 2020-2023 as well as 4 ongoing IPL Projects. The most important publications are listed in item 12 (References). Total 8 abstracts reporting CLG WCoE 2020-2023 activities and achievements are submitted to be presented at WLF6 in Florence, Italy. At least 3 chapters reporting CLG WCoE 2020-2023 activities and achievements will be submitted to ICL Open Access Book Series “Progress in Landslide Research and Technology” Vol.2.

Note: Please fill and submit this form **by 30 March 2023** to **KLC2020 secretariat** <klc2020@iclhq.org>